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THE EFFECTS OF DATABASES AS COGNITIVE TOOLS IN A MULTIMEDIA PROBLEM-BASED LEARNING ENVIRONMENT

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THE EFFECTS OF DATABASES AS COGNITIVE TOOLS IN A MULTIMEDIA PROBLEM-BASED LEARNING ENVIRONMENT

by

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THE EFFECTS OF DATABASES AS COGNITIVE TOOLS IN A MULTIMEDIA PROBLEM-BASED LEARNING ENVIRONMENT

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Computer-based cognitive tools can offer learners an intellectual partnership that transcends the limitation of human cognition, such as limitations to memory, thinking, and problem solving. Databases, for example, can function as cognitive tools because of their organized and searchable nature. The purpose of this study is to examine the potential of databases to function as cognitive tools to promote cognitive skill acquisition, share learners' cognitive load, and impact learning. A total of 98 students from 6 intact sixth grade science classes at a suburban middle school in the southern United States participated in the study. 57.9% of the participants were Caucasian, 24% were Hispanic, 18% were African American, and 0.01% were Asian. The six classes were assigned to one of three treatment conditions: (a) online database, (b) paper-based database, (c) no database. All groups completed a 3-week instructional program using the same version of

Alien Rescue, a multimedia learning environment, which contains the same content and tools. Measures of task difficulty rating, instructional efficiency, transfer, and factual knowledge recall were administered to evaluate learners' cognitive load, cognitive skills, and overall performance.

Students in online database groups received positive and higher instructional efficiency scores, which indicated a more efficient allocation of cognitive load. Online database groups also received significantly higher scores on cognitive skill transfer test than did students in both paper-based database and non-database groups. In addition, students in online database groups scored significantly higher on achievement tests than both the paper-based database and non-database groups. The results support researcher's hypothesis that the online database tool can reduce learners' extraneous cognitive load and increase learners' germane cognitive load; support the transfer of cognitive skills; and help learners perform better in a multimedia learning environment. However, future research is needed to confirm the results and to further investigate the effects of individual differences on learning using database tools.

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Chapter 1: Introduction

SIGNIFICANCE OF THE STUDY

Technology has gradually become a common and vital part of students' school experience and daily life. Many believe that the use of computers will shape the character of America's future generations.

> I think the experience of the Net generation with the digital media is changing human nature. Rather than following a broadcast-model world for entertainment, and a broadcast, talk-down, authoritarian world in the family and in the workplace, these kids are going to have a much more open, interactive, collaborative, verbal, thoughtful environment, and that will change the way they will be as adults. These kids will dominate the 21st century (Malanowski, 1997).

As the Department of Commerce has found in its Emerging Digital Economy reports,

> The dramatic growth of electronic commerce and the development of information technology (IT) industries are changing the way Americans work, communicate, purchase goods, and obtain information. Jobs in the new economy now increasingly require technical skills and familiarity with new technologies (The Emerging Digital Economy, 1998).

This dramatic change of future job requirements also calls for actions from American schools to increase the use of computers in classrooms. The federal government has financially supported the use of computers in public schools. A variety of programs were established to fund the purchase of computers by public schools. For instance, the E-rate program, administered by the Universal Service Administrative Company (USAC), provides significant discounts on telecommunications technologies to schools and libraries in the U.S.

However, do computers really impact students' learning outcomes? How do we design instruction and computer programs in ways that truly facilitate teaching and learning? These questions are still not fully addressed by educators and researchers. Much more research needs to be done in the field of instructional technology.

Early research on instructional technology mainly focused on what the technology can do to the learner or the *effects* of technology. Technology plays a rather passive role and is viewed as merely a delivery media that students learn *from*. This aspect is important. However, it is becoming increasingly clear that another aspect, which pertains to what students can do *with* the technology, needs to be considered by the researcher. Instead of being a mere delivery media, technology should offer learners an intellectual partnership that transcends the limitation of human cognition, such as limitations to memory, thinking, and problem solving (Pea, 1985). Computer-based cognitive tools, for example, are important to this way of conceptualizing relationships between users and computers.

Lajoie (1993) grouped computer-based cognitive tools into four categories. Tools that can support cognitive processing; tools that can share the cognitive load; tools that can engage learners in activities that would normally be out of reach; and tools that can support learners' hypotheses testing. Jonassen and Reeves (1996) further did a comprehensive review of a wide range of recognized computer-based cognitive tools that function as intellectual partners to facilitate learners' critical thinking and higher-order learning. Theses tools include but are not limited to databases, spreadsheets, semantic networks, expert systems, multimedia/hypermedia construction software, computer-based conferencing, collaborative knowledge construction environments, computer programming languages, and microworlds. However, during the analysis of the above cognitive tools, Jonassen and Reeves also pointed out that the effectiveness of some of the tools lack empirical evidence. Based on my literature review, there is an extremely limited research base on the effects of databases as cognitive tools.

This research study, therefore, intends to address the above problem and contributes to the research base for computer-based cognitive tools. The researcher will explore the effect of databases as cognitive tools in a multimedia problem-based learning (PBL) environment called Alien Rescue.

THE PURPOSE OF THE STUDY

This study will examine the effects of a computer-based cognitive tool – online database – designed for use within a multimedia Problem-Based Learning program. This tool offers a database template for learners to organize, compare, and evaluate their research data.

To use the database tool, students will be involved in various cognitive tasks. First, students will need to search the Alien Rescue knowledge base for information. In addition, they will need to discriminate between relevant and irrelevant information and locate the relevant information to be placed into the database table. Second, before entering information into the database, students will have to create categories based on the information they have gathered, and further organize the information under each category. Third, after a certain amount of information has been gathered and entered into the database, students will have the ability to perform queries for comparison of information from one table to another table. Through this function, students can form hypotheses, make connections and comparisons among various pieces of information, analyze and evaluate the query results, and develop a plan for future data collection and problem solving.

The purpose of examining the effects of this database tool is twofold. First, this study examined whether databases can function as cognitive tools. The database tool under investigation is designed in such a way that learners are responsible for all the planning, researching, thinking, and decision-making, while the tool supports learners' cognitive processing by sharing cognitive responsibilities that they do best such as storing information and allowing query constructions. For example, since this database tool helps learners store their research data and allows learners to further process their data at a deeper level through queries, the researcher proposed that the use of the database tool can share learners' cognitive load by reducing extraneous cognitive load and increasing germane cognitive load. Moreover, learners are engaged in a variety of cognitive tasks such as analyzing, comparing, and evaluating. Therefore, the use of the database tool may also facilitate learners' acquisition of those cognitive skills. According to Jonassen and Reeves (1996), building and using databases would help learners analyze and organize information, comprehend domain knowledge, and draw inferences. However, they were unable to locate any formal empirical research to validate the use of databases as cognitive tools. The database tool under investigation in this study may provide such an opportunity. The results of the study would indicate whether databases can be used as cognitive tools to support learning.

The second purpose of this study is to investigate the ability of the database tool to enhance learning. This tool is designed to be used within a multimedia PBL environment. In conjunction with other cognitive tools originally designed in the Alien Rescue program, this database tool can support and facilitate learner's cognitive processing and learning. Even though it was not specifically designed to support PBL, the researcher proposed that the effectiveness of its functions as a cognitive tool could contribute to learners' overall achievement in PBL environments.

In conclusion, the purpose of this study is to examine the potential of databases to function as cognitive tools to share learners' cognitive load, promote cognitive skill acquisition, and impact learning. The results of this study can be used to enrich our understanding of how databases function as cognitive tools to support learning, and contribute to the future design of database tools in computer-based interactive learning environments.

RESEARCH QUESTIONS

1. Do the online and the paper-based database tools under investigation share learners' cognitive load by reducing extraneous cognitive load and increasing germane cognitive load? Does the online database tool share learners' cognitive load more effectively than the paper-based database tool?
2. Do the online and the paper-based database tools under investigation facilitate students' acquisition of cognitive skills such as organizing, categorizing, analyzing, and evaluating? Does the online database tool facilitate learners' cognitive skill acquisition more effectively than the paper-based database tool?
3. Do the online and the paper-based database tool under investigation affect learners' performance in a hypermedia PBL environment? Does the online database tool improve learners' performance more effectively than the paper-based database tool?

TERM IDENTIFICATION

Databases are computer-based record keeping systems that were developed originally to replace paper-based filing systems. A database consists of one or more files. Each file contains a set of records. Each record is divided into fields. Databases allow users to manage, search, sort, as well as answer queries about information in it.

Cognitive tools are any tools or instruments that support and enhance the cognitive power of learners during thinking, problem-solving, and learning.

Problem-based learning is an instructional approach which uses problem as focuses of learning.

Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time.

Extraneous cognitive load is also called ineffective cognitive load. It refers to the demand imposed on working memory by the manner in which materials is presented and the activities required of the learner.

Germane cognitive load also impose extra cognitive load on learners. However, this extra cognitive load contributes to learning because the extra mental efforts are directly relevant to schema construction.

Multimedia / Hypermedia refers to computer applications that contain multiple media formats (text, audio, video, graphics, and animation) in a non-linear structure.

Chapter 2: Literature Review

The design of the database tool under investigation in this study is informed by a wide range of literature on learning and cognition theories. In this chapter, I will review literature on cognitive developmental theory, information processing theory, cognitive load theory, cognitive skills and their acquisition, and computer-based cognitive tools. Other related learning theories such as dual-coding theory and constructivist learning theory will also be addressed.

COGNITIVE LEARNING THEORY

Within the last two decades, cognitive psychology has become the predominant perspective for learning research and theory. Unlike behaviorism which focuses on stimuli and responses, this approach focuses directly on human cognitive processes, "considering how people perceive, interpret, remember, and otherwise think about the environmental events they experience" (Ormrod, 1999 p. 145). It is believed that learners' cognitive processes are centrally involved in their learning and thus should be the major concern of educational researchers. Cognitive researchers view learning as mental processes of relating new information to previously learned information, and look at *how* students are trying to learn (Ormrod, 1999). Cognitive learning theory evolved from this perspective. It views learning as any process that modifies a system so as to improve its subsequent performance of the same task or of tasks drawn from the same population (Ormrod, 1999). The major differences of cognitive versus behaviorist concept of learning are the emphasis on the performance of a system instead of the behavior of an individual; the emphasis on the various stages and processes involved in human information processing rather than on how changes in knowledge take place; and finally the emphasis on mental processes and knowledge structures rather than on behavior.

Although cognitive psychology has become the predominant perspective for learning research and theory during the last two decades, it is under constant modification and refinement. New cognitive perspectives have emerged over time. In this section, I will examine cognitive developmental theory, information processing theory, as well as cognitive load theory and dual coding theory, two rather new cognitive perspectives evolved from information processing theory.

Cognitive Developmental Theory

Cognitive developmental theory is often referred to as Jean Piaget's cognitive developmental theory. Piaget is the father of cognitive developmental theory. His contribution to developmental psychology is far and foremost. Cognitive developmental theory is mainly concerned with two major questions: what cognitive processes are responsible for changes in a child's development? What stages of cognitive development do children move through? Cognitive developmental theory emphasizes the development of children's rational thinking and stages of thought. Environmental experiences are important, but they are mainly the "food" for children's cognitive structure. From cognitive developmental theorists' view, thoughts are the primary determinants of children's action, and thus should be the central focus of development (Santrock & Yussen, 1992).

The aspects of Piaget's work that have received the most attention from educators are those describing differences among children at different ages – the stage theory. Piaget believed that we go through four major stages of cognitive development. The four developmental stages together with the approximate ages to which they correspond are demonstrated in table 2.1. In the following discussion, I will put more focus on the last two stages due to the target population of this study.

Table 2.1 Developmental Stages and Corresponding Ages

Stage	**Age**
Sensorimotor	Birth to 2 years
Preoperational	2 to 7 years
Concrete operations	7 to 11/12 years
Formal operations	11 or 12 to 14 or 15 years

From Lefrancois, 1982. p. 192-193.

The Sensorimotor Stage

Piaget characterized the first two years of life as the sensorimotor stage. During this stage, children develop the ability to organize and coordinate their sensations and perceptions with their physical movements and actions. This type of coordination of sensations with actions forms the sensorimotor intelligence (Santrock & Yussen, 1992).

Baldwin (1967) described children's three accomplishments by the end of the sensorimotor period. The first is the acquisition of internally controlled schemas. By the age of two, most children have made the transition from merely motor and perceptual representation of the world to a more symbolic representation. They have established a controlled internal representation of the world around them. The second achievement is the development of the object concept. In other words, children discover that objects continue to exist even when they are not seen, felt, heard, smelled, or tasted. The final achievement at the end of this stage is the recognition of cause-and-effect relationships. Such recognition is the prerequisite to form intentionality. Piaget views intention closely linked to intelligence, because intelligent activities are always intentional. These three accomplishments prepare children for the next stage of development: the preoperational stage.

The Preoperational Stage

The preoperational stage lasts from approximately two to seven years of age. In this stage, children begin to represent the world with words, images, and drawings. However, children at this age still lack the ability to perform operations – the internalized mental actions that allow children to do mentally what they previously did physically in the first stage (Santrock & Yussen, 1992). Therefore, this stage is called the preoperational stage.

Children at the preoperational stage have made substantial improvements in thinking skills. However, their thought is preoperational and thus has several limitations (Schiamberg, 1988). Preoperational thinking is generally concrete, non-reversible, and egocentric. Children work best with their immediate surroundings and are mainly aware of the environment from their own perspective. In addition, they are incapable of considering multiple dimensions of a problem simultaneously. Although preoperational thinking is limited, it does prepare children's cognitive skills and structure for the next stage of development – the concrete operation stage.

Concrete Operations Stage

The concrete operational stage is the third stage of children's cognitive development. Concrete operational thought appear somewhere between seven to eleven or twelve years. It is considered as a transition phase rather than a final phase because the development of children's operational intelligence is still not complete (Brainerd, 1978). During this period, children can perform operations and use operations to solve problem. However, their thinking still needs to be tied to what is observable, in other words, concrete examples. Therefore, this stage is called concrete operations stage. Major characteristics of concrete operations stage are described as follows (Lefrancois, 1982).

- The ability to classify objects. Unlike children at the preoperational stage, the concrete operational children can classify objects in terms of multiple dimensions simultaneously. They are also capable of organizing objects into hierarchies that include nested classes.
- The ability to arrange objects along a continuum of increasing or decreasing value (seriation). Before this stage, children can rank objects by comparing two of them at once; but they cannot make the inference that if *A* is greater than *B* and *B* is greater than *C*, then *A* must be greater than *C*. The concrete-operations children, however, can make a whole serial arrangement among multiple objects.
- The ability to return to the original circumstances (reversibility). In preoperations stage, children's thoughts are non-reversible, which means they cannot return to the starting point of a given thought process. While children in the concrete operations stage have the ability to reverse their thoughts.
- The ability to deal with numbers. This ability derives from the ability to classify and seriate. As a result of the acquisition of logical operations, children at this stage are able to deal with concepts and numbers.

According to the above description, children at the concrete operations stage overcome a lot of the limitations of the preoperational stage. They are able to think in terms of numbers, classes, and relationships. However, it still has certain limitations.

For example, children can only uses mental operations in the context of concrete things. They can not think abstractly or hypothetically like adolescents. These cognitive skills appear in the next stage of cognitive development: the formal operations stage.

Formal Operations Stage

Formal operations stage is the final stage of cognitive development. It appears somewhere between eleven or twelve to fifteen years, and goes into adulthood. At this stage, adolescents have become scientific thinkers who are capable of reasoning in abstract terms, simultaneously considering several factors in problem solving, and developing and testing hypothesis. The characteristics of formal operational stage are illustrated as follows (Schiamberg, 1988).

- The ability to think about the *possible* as well as the *real*. Adolescents are not limited to dealing with things as they are. Rather, they can now deal with things as they might be in hypothetical terms.
- The ability to form and test hypotheses about the solution to a give problem. Adolescents are capable of testing hypothesis one after another systematically until a solution is discovered.
- The ability to deal many facts simultaneously. Adolescents recognize that there are multiple factors pertaining to a single problem, therefore, they need to deal with multiple interrelated determinants.

- The ability to use abstract logic. Formal operations are not operations directly deal with concrete objects. Rather, they deal with manipulations of propositions, statements, or symbols that are abstract or derived from the concrete reality.
- The ability to think introspectively about one's own thoughts. Adolescents understand that their thoughts are private, and it is their decision whether to share them with others or not.

These characteristics clearly indicated that formal operational thoughts are much more advanced than concrete operational thought. In fact, this stage goes all the way to adulthood. There will be no more significant developmental changes from this stage on. Yet, intelligence continues to grow due to experience and learning. Table 2.2 illustrates the major differences between concrete operational and formal operational stage.

Table 2.2 A Comparison of Concrete Operational Stage and Formal Operational Stage

Concrete Operational Stage	**Formal Operational Stage**
Thought limited to concrete objects and situations	Thought extended to ideas as well as concrete reality
Problem solving dictated by details of the problem	Problem solving dictated by planned hypothesis testing
May be able to handle one or two factors at a time	Can handle multiple factors simultaneously
Thought focused on one's own perspective	Thought enlarged to perspectives of others

Modified from Schiamberg, 1988, p. 673.

By now, thousands of studies have investigated and elaborated on Piaget's stage theory (Lefrancois, 1982). An overwhelming majority of studies supports Piaget's general description of the developmental stages (Gelman, 1978). However, some research and findings have not been entirely similar to what Piaget described, especially on his age group definition for concrete and formal operational stages. A number of studies provided convincing evidence that formal operational thoughts fail to be present among adults, let alone adolescents (Dulit, 1972; Gelman, 1978). Dulit (1972) investigated evidence for formal operations on gifted older adolescents. He found that about half of the adolescents still functioned at the level of concrete operations. Only approximately one-quarter of the average older adolescents and adults actually functioned at a formal operational level. Cross-cultural studies also yielded similar results (Gelman, 1978).

As a result of these research findings, Piaget (1972) revised his earlier theory on formal-operational stage and concrete operational stage. He pointed out that formal-operational stage cannot be generalized to a specific age group such as adolescents or adults. In fact, formal operations are probably impossible in middle childhood or earlier. Formal operations should be viewed as cognitive processes that are possible and potential rather than probable.

The impact of Piaget's theory on school curricula and instructional procedures are profound and significant. Based on Piaget's stage theory, children at different ages have consequent limits of cognitive abilities. Instructional materials and activities, therefore, need to be structured and presented at optimal level of difficulty.

For example, if we plan to design a problem-based learning environment that requires 6^{th} graders (age 11-12) to perform sophisticated research and hypothesis testing, we have to be aware of their cognitive limitations. According to Piaget, children at the age of 11 or 12 are at the transitional phase from concrete operations to formal operations. Moreover, as we mentioned before, a large percentage of the children are actually not performing at the formal operational level even when they approach adulthood. Therefore, while designing learning environments for 6 graders, we have to carefully consider the cognitive limitations of concrete operational thought. At this stage, children are not fully ready to perform hypothesis testing or to deal with multiple factors simultaneously. In other words, they are not good at planning and testing hypothesis for problem solving. Consequently, we should either not include such activities in the learning environment, or we need to provide learners with appropriate cognitive tools within the environment that share their cognitive responsibilities and support their performance on those difficult cognitive tasks. Databases, for example, may be suggested as one of those cognitive tools.

Cognitive developmental theory provides profound insights for the design of instructional activities or learning environments. However, it is not adequate to explain all aspects of learning. Other cognitive learning theories also need to be considered. We will now turn to information processing theory.

Information Processing Theory

The cognitive developmental theory describes how children structure thought at different ages. However, this description is rather general. It doesn't inform us much about how children read, learn new concepts, or solve problems. A lot of important details about how the human mind works on specific tasks such reading, writing, and problem solving are left unexplained. Information processing theory attempts to fill those gaps. It provides a framework for understanding how human/children learn and think. It assumes that, in order to understand how humans learn and think, we need to analyze the way humans accept and take information (sights, sounds, smells, and so on), how they store information, and how they retrieve and use it for some clearly defined purposes or goals (Santrock & Yussen, 1992). Therefore, information processing theory describes mental processes and offers details about how these processes work in real-life situations.

Stages of Information Processing

Memory is one's ability to recall information that has been previously learned. It plays an important role in learning. Cognitive learning theorists have identified three stages of memory during information processing: sensory memory, short-term memory, and long-term memory (Ormrod, 1999).

Sensory memory is the first stage of information processing. It accepts sensory inputs such as vision and hearing, and holds information in memory for a very brief period, just long enough for the information to be processed further. There is a separate sensory memory for each of the five senses: sights, sounds, smells, tastes, and touches. Each sensory memory is assumed to work in the same way and extinguish rapidly. During that time, we have to identify and assign meaning to the new information; otherwise it will be gone forever.

Short-term memory is also called working memory. It is the second stage of information processing. During this stage, further processing is carried out to prepare the information for long-term storage or a response. Working memory can also be equated with consciousness. When humans are actively thinking about and conscious of certain things, those things are in the working memory. However, working memory can only hold limited information in a limited amount of time. According to Miller (1956), working memory is only capable of holding seven items or elements of information at a given time. Overextending working memory with more than seven chunks of information at one time leads to confusion or forgotten information; whereas seven or fewer chunks of information can be processed efficiently to better facilitate the transfer to long-term memory. Moreover, working memory is always used to process information at a higher level than sensory memory, such as organizing, contrasting, comparing, and so forth. In this case, humans are probably only capable of dealing with fewer than seven items simultaneously. Any interactions between elements in the working memory can reduce the number of elements that can be dealt with at a give time.

Long-term memory is the third stage of information processing. It is the permanent storage place for information. Long-term memory is also the network of association, otherwise known as the individual's schema. Schema will be discussed further in the later sections. Although humans have limited working memory, their long-term memory is capable of retaining an unlimited amount of information. However, in order for information to be stored in the long-term memory, it has to be transferred from working to long-term memory. It needs to be attended to, and processed by, working memory.

Flow of Information Processing

In order for the information to be processed and stored in the long-term memory, it has to pass from one stage of memory to the next. At first, sensory memory accepts sensory inputs and holds information for a brief period. Then, individuals pay attention to selected input information and further process it. The limited information is stored in the working memory for a limited amount of time. Afterward, for information to reach a relatively permanent state in long-term memory, it has to be encoded. In other words, individuals need to process the incoming information and make connections with relevant knowledge already in the long-term memory. Therefore, information will be more memorable and will be fully processed and encoded into the long-term memory.

Finally, once information has been stored in the long-term memory, it can be retrieved for later use. In order to understand new information or make a response, individuals have to retrieve part of the information from long-term memory and fill in holes based on what is logical or consistent with their existing knowledge of the world (Driscoll, 2000).

Schema

Schema is a very important concept in information processing theory. A schema is an organized body of knowledge about a specific topic (Ormrod, 1999). According to schema theory, knowledge is stored in long-term memory in the form of schemata. Schemata provide elements of knowledge and further categorize elements of information based on the manner in which they will be used (Chi, Glaser, & Rees, 1982). Schemata are active in influencing how people interpret events, solve problems, and acquire knowledge. The construction of schema has two major functions in knowledge acquisition and learning: to organize and store a huge amount of information, and to reduce working-memory load.

Schema provides a mechanism for knowledge organization and storage. By combining elements consisting of lower level schemas into higher level schemas, individuals can continue building increasing numbers of increasingly complex schemas (Sweller, van Merrienboer, & Paas, 1998). Thus, information elements are better integrated and organized, and require less storage. Moreover, schemas can help reduce working-memory load. As we mentioned before, the working memory can only process a limited number of elements at one time. However, even though the number of elements is limited, the size, complexity, and sophistication of elements are not. For example, a schema can consist of a significant amount of very complicated information, yet it is only treated as a single element in working memory. Therefore, there are no apparent limits on the amount of information that can be processed in the working memory simultaneously, if the information is stored and organized in a schema. Schema construction aids the organization and storage of information in long-term memory and reduces working memory load.

Furthermore, knowledge as well as intellectual skills based on knowledge is heavily dependent on schema acquisition and construction. For example, Sweller and Chandler (1991) pointed out that the main difference between novices and experts in problem-solving skill is that novices solve problems using means-end analysis, while experts use previously acquired schemas. Schemas provide basic units of knowledge. The operation of schemas can be used to explain a substantial proportion of our learning-mediated intellectual performance. According to the schema theory, facilitating schema acquisition and construction should be a primary goal for instruction and learning.

If schemas are crucial for learning, what conditions are most likely to facilitate their acquisition? Over the past two decades, Cognitive Load Theory (CLT) has evolved from information processing theory and has been used to investigate some conditions that need to be considered to construct powerful schemas.

Cognitive Load Theory

Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time (Cooper, 1998). Cognitive Load Theory is based on cognitive theories of human cognitive architecture that deal with the mental process of learning, memory, and problem-solving. It assumes a limited working memory that is connected to an unlimited long-term memory and the function of schema to reduce working memory load. As a result, CLT is concerned with the limitations of working memory and is interested in the measures that can be taken to facilitate schema construction and free working memory load by imposing appropriate levels of cognitive load. Working memory load is affected by the inherent nature of the material (intrinsic cognitive load), the manner in which the material is presented (extraneous cognitive load and germane cognitive load), and the effort that is used towards schema construction (germane cognitive load).

Intrinsic Cognitive Load

Intrinsic cognitive load is associated with the nature of the instructional materials. Instructional materials can have substantial influences on the working memory load. The working memory load imposed by instructional materials depends on the number of elements that has to be processed simultaneously in the working memory. Generally speaking, materials with "low element interactivity" do not require as extensive use of working memory resources as materials with "high element interactivity" (Sweller, van Merrienboer, & Paas, 1998). An example of the former occurs when a non-native speaker is learning English vocabulary. This is a difficult task because there are a large number of vocabulary items to be learned. However, it may not impose a heavy cognitive load on working memory, since each new word may be learned without referencing other words. The task of learning the word "dog" can be accomplished without learning the word "cat". Learning this type of material is associated with a rather low intrinsic cognitive load.

High element interactivity tasks, however, are at the other end of the continuum. Several elements have to be manipulated in working memory at the same time. For example, while comparing and contrasting scientific facts of different planets in the solar system, learners have to hold several interacting elements in working memory simultaneously. Consequently, extensive use of working memory load is needed.

Nevertheless, the level of element interactivity cannot be solely determined by the nature of the instructional material. As we mentioned above, once a schema is constructed, interrelated elements can be incorporated within the schema. Thus, those elements will not be treated individually within working memory. Rather, the schema will act as a single entity in working memory and impose much less of a working memory load. As a result, a large number of interacting elements may pose a tremendous working memory load on novice learners, while requiring minimal working memory resources from experts. Thus, intrinsic cognitive load is determined by the level of element interactivity of the instructional material and the expertise of the learners (Sweller, van Merrienboer, & Paas, 1998).

Although intrinsic cognitive load adds to learners' working memory load, it cannot be directly altered or influenced by instructional interventions. Extraneous cognitive load, however, can be reduced through instructional design. Therefore, cognitive load theorists put great emphasis on extraneous cognitive load and ways to control it.

Extraneous Cognitive Load

Extraneous cognitive load is also called ineffective cognitive load. It refers to the demand imposed on working memory by the manner in which materials is presented and the activities required of the learner (Sweller, van Merrienboer, & Paas, 1998). Extraneous cognitive load, which has its roots in poorly designed instructional materials, reduces the working memory capacity for learning.

Many commonly used instructional designs and procedures impose on learners a high extraneous cognitive load which is not relevant for learning. These cognitive loads are extraneous because they are normally generated by the instructional format rather than the intrinsic characteristics of the material (Sweller, Chandler, Tierney, & Cooper, 1990). For example, consider a student who is asked to solve a means-end problem, which requires him to consider a current problem state, a single goal state, extract the differences between the two states, and find a problem-solving operator. This type of instructional activity does not relate very much to learning because learners put too much emphasis on the problem goal rather than on learning itself. A heavy cognitive load is imposed on learners and interferes with learning. Therefore, this cognitive load constitutes an extraneous cognitive load.

Consider another example where the instruction incorporates multiple sources of information such as a combination of mutually referring diagrams, text, or even video/audio resources. In order to understand the diagram, the text, or the video, learners have to integrate them mentally. Such mental integration is very likely to impose a fairly heavy extraneous cognitive load. However, multiple sources of information are not always bad. In fact, we may even maximize learning through both verbal (e.g. audio, words) and visual (e.g. graphics, diagrams) modes of representations. I will discuss how instruction can be designed with multiple sources of information when discussing dual coding theory.

In general, whenever working memory resources may be used for activities that are irrelevant to schema acquisition and construction, they will impose a heavy extraneous and ineffective cognitive load. Additionally, extraneous cognitive load and intrinsic cognitive load are additive (Sweller, van Merrienboer, & Paas, 1998). If there is a combination of high extraneous and high intrinsic cognitive load, working memory may be significantly exceeded and thus impede learning. Since intrinsic cognitive load cannot be modified, it is crucial to design instruction in a way that reduces extraneous cognitive load, especially when element interactivity is high.

When both intrinsic and extraneous cognitive load are low, part of learners' working memory is freed to process other tasks. In such cases, we might want to encourage learners to devote more mental effort to processes that are directly related to learning and schema acquisition. This type of process will also increase cognitive load, yet it is germane cognitive load that will actually contribute to learning.

Germane Cognitive Load

Both germane cognitive load and extraneous cognitive load impose extra cognitive load on learners. While extraneous cognitive load interferes with learning, germane cognitive load enhances it. The assumption of germane cognitive load is that instructions are designed to have a low intrinsic cognitive load and a low extraneous cognitive load. Therefore, the remaining resources in the working memory may be used to engage learners in conscious cognitive processing that is directly related to schema construction

Van Merrienboer (1997) pointed out that the combination of decreasing extraneous cognitive load and increasing germane cognitive load involves redirecting attention. This combination requires that the learner's attention be withdrawn from processes that are not relevant to learning and be directed toward processes that are relevant, especially toward the construction and acquisition of schemas. For example, if the instruction incorporates a large amount of multimedia content, it may impose a heavy extraneous cognitive load. However, if activities or instructional procedures are designed in such a way that they help students organize information, make connections among concepts, form and test hypotheses, and draw inferences, the students' attention will be redirected to cognitive processes that are directly relevant to the construction of schemas. Appropriate instructional designs can reduce extraneous cognitive load and increase germane cognitive load.

Since intrinsic, extraneous, and germane cognitive loads are additive, the total cognitive load cannot exceed the working memory resources. If they do, learning will not occur (Paas, Renkl, & Sweller, 2003). The amount of each cognitive load that can be imposed on learners is mutually dependent on other cognitive loads. Intrinsic cognitive load provides a base load that is normally uncontrollable and irreducible. After resources have been allocated to intrinsic cognitive load, the remaining working memory capability can be used to deal with extraneous and germane cognitive load. Furthermore, a reduction in extraneous cognitive load by certain instructional procedures or activities can free additional working memory resources to deal with germane cognitive load. Finally, the increase in germane cognitive load can help learners construct and acquire more advanced schemas, which in turn, will free more working memory capacity by incorporating lower-level schemas within higher-level schemas that include a large number of elements. This cycle can help learners acquire more advanced skills and knowledge over time.

In summary, the primary goal of Cognitive Load Theory is to provide a framework to support the design of instructional procedures and activities that effectively manage cognitive load to enhance learning. In the following section, I will further discuss three different approaches to manage cognitive load and the instructional procedures that support them.

Managing Cognitive Load

Reduction of Extraneous Cognitive Load

Traditionally, CLT focused on instructional techniques that can be used to decrease extraneous cognitive load. It identified several cognitive processes that yield a fairly high extraneous load, such as applying means-end analysis in problem solving, mentally integrating physically separate sources of information, and dealing with redundant information (Van Merrienboer, Schuurman, Croock, & Paas, 2002). For example, Sweller (1988) pointed out that means-end analysis in problem solving is not effective because cognitive resources are devoted to a whole range of activities that are irrelevant to schema acquisition. Thus, according to CLT, by preventing students from using means-end strategies, instructors can encourage them to focus on problem states and their associated moves, and thus reduce extraneous cognitive load and facilitate schema construction. Over the past 15 years, several instructional techniques were proposed by cognitive load theorists to reduce extraneous cognitive load based on multiple, overlapping experiments using a variety of materials and populations.

The Goal-Free Effect

According to Sweller (1988), problem-solving through means-end analysis may be an effective way to attain a problem goal without support of a schema. However, it is a process that requires a large amount of working memory capacity, which requires minimal schema construction. Thus, a heavy extraneous cognitive load is imposed. To respond to this problem, the goal-free effect was proposed. Sweller and Levine (1982) devised goal-free problems, which modified problem-solving activities by eliminating the means-end search. Goal-free problems do not allow learners to compare and extract differences between the current problem state and the goal state because there is no goal state in the problem. Thus, in order to solve the problem, learners have to use strategies that do not rely on a means-end analysis. One of the most used alternative strategies is to consider each problem state and find any problem-solving operator (a rule for algebra) that can be applied. Once an operator has been applied, a new problem state will be generated, and the process can continue until the problem is solved (Sweller, van Merrienboer, & Paas, 1998). The effectiveness of goal-free problems was supported by many experiments (Sweller, Mawer, & Ward, 1983; Owen & Sweller, 1985; Vollmeyer, Burns, & Holyoak, 1996).

Sweller, Mawer, and Ward (1983) conducted several experiments using kinematics and geometry problems with secondary students. For instance, a conventional geometry problem may ask students to find the value of a particular angle in a diagram, while the goal-free problems require students to find the values of as many angles as they could. During those experiments, both conventional and goal-free groups followed the same general procedure, except that goal-free groups used goal-free problems rather than conventional means-end problems in the practice session. Tests using conventional problems were used to assess students' learning. The results consistently showed that goal-free groups achieved better schema construction than conventional groups. According to the researchers, while using means-end analysis, the learner has to continually hold and process in working memory the current problem state, the goal state, relationships between them, problem-solving operators, and sub-goals. On the contrary, while solving goal-free problems, the learner only needs to hold and process the current problem state and the operators can be applied to that state. Thus, goal-free problems significantly reduce cognitive load and facilitate learning. Similar results were obtained by Owen and Sweller (1985) and Vollmeyer, Burns, and Holyoak (1996).

Due to the strong evidence for the effectiveness of goal-free problems, the design was considered an important technique while dealing with problem solving that requires practices.

Worked Example Effect

Studying worked examples also eliminates the use of means-end analysis; however, the techniques are different from goal-free problems. The former uses a large number of worked examples as a substitute for solving problems. Worked examples focus attention on problem states and their associated moves, and thus facilitate acquisition of schemas and impose a low extraneous cognitive load.

Evidence of the use of worked examples to facilitate learning and reduce extraneous cognitive load was found in several studies. Sweller and cooper (1985) and Cooper and Sweller (1987) studied the use of worked examples in algebra as a substitute for conventional problem solving techniques. The results showed that the use of worked examples improved schema construction and learners' abilities to solve new algebra problems. Worked example groups had a reduction in acquisition time and a superior test performance. In recent studies, Paas and van Merrienboer (1994) found that when students only had to study worked examples instead of conventional problems, they had lower extraneous cognitive load scores, higher transfer performance, and better schema construction. Trafton and Reiser (1993) also found that college students who studied aspects of the LISP programming language benefited more after studying worked examples than after solving comparable conventional problems.

Studies on the use of worked examples to reduce extraneous cognitive load yielded consistent results. Most studies concluded that a heavy use of worked examples can benefit learning and transfer. However, there are also disadvantages to the use of worked examples. For instance, the design of good worked examples is quite difficult.

In addition, a heavy use of worked examples may even impede the generation of creative, new ways of solving problems by providing learners with stereotyped solution patterns (Sweller, van Merrienboer, & Paas, 1998). Therefore, cognitive load theorists also suggested the use of completion problems as an alternative to worked examples.

Completion Problem Effect

Van Merrienboer and Krammer (1987) introduced the use of completion problems to reduce extraneous cognitive load. Completion problems provide learners with a given state, a goal state, and a partial solution. Learners must then complete the partial solution. Completion problems combine the strong points of both worked examples and conventional problems, and thus contribute to decrease extraneous cognitive load.

Van Merrienboer (1990) conducted a study to compare the effect of a completion-problem-based instructional strategy and the effect of a conventional-problem-based instructional strategy in a ten-lesson introductory computer-programming course. The data analysis showed that the completion group performed significantly better on the construction of new programs. Moreover, the use of completion problems facilitated students' use of programming templates, which is an obvious representation of better schema construction. Van Merrienboer (1992) summarized the results of studies on completion problems. He pointed out that, compared to conventional problems, completion problems help to decrease extraneous cognitive load, facilitate schema construction, and lead to better transfer. They are equally effective as worked examples, and may even provide better support to learners by helping them focus their attention on useful solution steps.

However, like worked examples, completion problems are also difficult to construct and time-consuming. For example, decisions on which part of the solution should be presented to and which part should be left for learners to complete are always hard to make.

The Split-Attention Effect

The split-attention effect derived from the worked example effect. Sweller and Chandler (1991) pointed out that not all worked examples can effectively reduce extraneous cognitive load in comparison to means-end analysis. In fact, worked examples can be ineffective because they may impose a heavy, extraneous cognitive load, especially when learners' attention is split among disparate sources of information that need to be integrated. The split-attention format requires students to use working memory to mentally integrate various sources of information, and thus imposes a heavy extraneous cognitive load.

The evidence of the split-attention effect was proved by many experiments using both worked examples and other instructional formats. Sweller, Chandler, Tierney, and Cooper (1990) demonstrated the split-attention effect using worked examples as well as more general instructional formats in coordinate geometry and numerical control programming. Chandler and Sweller (1992) provided similar evidence on split-attention effects that occur in the writing of scientific reports. More recently, Sweller and Chandler (1994) and Chandler and Sweller (1996) investigated the split-attention effect involving the use of a manual alone versus the use of both a computer and a manual for students to learn a computer application. The results showed that students learned better with the manual-only format. The researchers suggested that the use of both a computer screen and a manual resulted in split-attention. The researcher also pointed out that it is split-attention that causes the problem, not the use of a computer.

Split-attention effects occur very commonly in instructional contexts. The empirical evidence strongly suggests the need to provide integrated conditions. Split-attention has to be seriously considered by instructional designers.

The Redundancy Effect

The redundancy effect derived from the split-attention effect. Just like the fact that not all worked examples are effective unless the disparate sources of information are integrated, integration of all information sources may not always be effective in reducing extraneous cognitive load. If redundant sources of information are integrated, the effects can even become negative rather than positive (Chandler & Sweller, 1991).

The evidence for the redundancy effect was also supported by many studies. Chandler and Sweller (1991) investigated the redundancy effect using electrical engineering and biology instructional materials. The results showed that instructions that are designed to eliminate redundancy, or allow learners to ignore the redundant information achieved the best results. Students who were not presented with redundant information performed better on test than students who were presented with redundant materials. A recent study by Kalyuga, Chandler, and Sweller (1998) gained some interesting findings on redundant effect. Novice electrical apprentices were provided with a wiring diagram, where there was a textual description of the same diagram. The textual description only re-described the diagram and was considered as redundant information. The results showed that for the novices, the redundant information (textual description) actually was essential to their learning. They could not understand the circuit diagram by itself and did need the text explanation. However, for experts, the textual material was redundant and should be eliminated from the diagram. Thus, the study implicated that some information, although redundant to more experienced learners, may be essential for novice learners.

Sweller, Van Merrienboer, and Paas (1998) pointed out that redundancy effects should be dealt with seriously rather than ignored. The redundancy effect imposes extra extraneous cognitive load on learners' working memory and has substantial, negative consequences. However, as Kalyuga, Chandler, and Sweller (1998) found out, redundant information may not always interfere with learning. We will discuss more about this effect in dual coding theory.

Increasing Germane Cognitive Load

Traditionally, cognitive load theory has primarily studied instructional techniques and activities to reduce extraneous cognitive load. However, recent studies have focused on increasing germane cognitive load, while the total amount of cognitive load stayed within the working memory limits due to low intrinsic cognitive load or low extraneous cognitive load.

Germane cognitive load was considered directly related to schema construction. The basic assumption is that the design of instruction results in unused working memory capacity due to the low intrinsic cognitive load imposed by the instructional materials and/or the low extraneous cognitive load imposed by appropriate instructional procedures and techniques. In this case, learning maybe further improved by encouraging learners to actively engage in conscious cognitive processing that is directly relevant to schema construction (Bannert, 2002). However, this approach can only work if the total cognitive load does not exceed working memory limits – the total of intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

Since this approach is rather new, there are only a few studies investigating germane processes of schema construction (Van Merrienboer, 1997; DeCroock, Van Merrienboer, & Paas, 1998). Van Merrienboer, Schuurman, de Croock, and Paas (2002) did a very important study in this perspective. They investigated the effect of redirecting learners' attention on both extraneous and germane cognitive load as well as on learning results and training efficiency. Contextual interference**,** training conditions in which certain contextual factors prohibit a quick and smooth mastery of skills being trained, was used as a means to increase germane cognitive load. The researchers believed that high contextual interference yields better retention and transfer because learners have to invest more mental effort and elaborate information more deeply, and thus support schema construction and acquisition. Even though the cognitive load is increased, it is considered as useful, germane cognitive load, because the increase cognitive load is directly related to learning. Their study consisted of three experiments.

In the first experiment, the researchers compared completion problems, conventional problems, and a learner-controlled condition in which learners may choose between problem formats. Twenty six first year communication science students were randomly assigned to the three groups. A computer-based learning environment, completion assignment constructor (CASCO), was used as the instructional material. A 9-point symmetrical rating scale was used to measure learners' mental effort. And a troubleshooting task was used to measure transfer. Learners in the completion group finished the largest number of problems. This difference is statistically significant ($p<0.001$). In addition, the conventional group reported the highest cognitive load, followed by the learner control group and the completion group. However, even though both the completion and the learner control groups outperformed the conventional group on transfer tasks ($p<0.05$), this difference is only significant for the learner control group. The results showed that the completion group had lower cognitive load than the conventional group. Nevertheless, the completion group showed equal transfer test performance and even a tendency to outperform the conventional group. Thus, higher training efficiency was found in completion problem group. The second experiment is more interesting. High contextual interference was compared with low contextual interference. In this study, contextual interference describes training conditions where some intertask contextual factors (e.g. problem practice schedule) prohibit a fast and smooth mastery of skills being trained. Sixty nine first year Engineering students were randomly assigned to a low contextual and high contextual interference group. A computer-based simulation of a water-alcohol distillery plant was used for instruction. Learners were asked to practice 20 problems, and after the completion of each problem, they were asked to rate the amount of mental effort they invested in the problem. The results showed that high contextual interference group ($M=5.45$) had significantly higher cognitive load ($P<0.01$) than low contextual interference group ($M=4.85$), and showed a trend towards higher transfer performance. Thus, the high contextual interference group yielded higher transfer performance than the low contextual interference group, however; learner in high contextual interference group also invested more mental effort. In the third experiment, the researchers tried to redirect learners' attention from extraneous to germane cognitive process by combining the completion problem and high contextual interference method. A 2x2 factorial design was used with problem format factors (completion, conventional) and contextual interference factors (low, high). Eight seven first year students in Educational Science and Communication Science were randomly assigned to the four groups. CASCO was used again as the learning environment. The results were partly in line with the hypothesis. It was found that the combine method led to the highest training efficiency. Moreover, the completion condition had higher training efficiency than the conventional condition ($p<0.001$). However, contextual interference yielded no significant effects on training efficiencies. In addition, the expected high transfer performance was not found. In conclusion, Van Merrienboer et al. concluded that training efficiency was highest for the completion group working under high contextual interference, which is the group in which attention was redirected. Thus, they suggested that redirecting learners' attention by minimizing extraneous cognitive load and stimulating germane cognitive load is a promising means to improve learning and training efficiency as well as reach higher transfer performance. However, there are many instructional methods to reduce extraneous cognitive load and increase germane cognitive load. Not all combined methods are equally effective. More research needs to be done to investigate the most effective combined methods.

The current approach to increase germane cognitive load is rather new comparing with the traditional approach to reduce extraneous cognitive load. There is only limited empirical evidence on the effect of increased germane cognitive. More studies need to be done to investigate different methods to stimulate germane cognitive load. Combined methods of reducing extraneous cognitive load and increasing germane cognitive load also need to be further explored.

Manipulating Intrinsic Cognitive Load

According to cognitive load theory, intrinsic cognitive load cannot be manipulated by instructional designers. Element interactivity is intrinsic to the instructional material and thus cannot be altered. However, a completely new approach emerged recently arguing that intrinsic cognitive load can be manipulated, and intrinsic cognitive load can be reduced with the help of appropriate information sequencing (Bannert, 2002).

Pollock, Chandler, and Sweller (2002) investigated the manipulation of intrinsic cognitive load while learning highly complex information. During the first part of the instruction, cognitive load was artificially reduced by not presenting the whole information at once. Instead, individual pieces of information that could be processed sequentially were offered. Later, in the second part of the instruction, all information was presented at once to the learners so that it had to be processed simultaneously in working memory. The results showed that this mixed method significantly improved learning and training efficiency, comparing with instructional formats which present all information at once from the very beginning. The researchers pointed out that in order to allow novice learners to process very complex information that consists of highly interacting elements, the intrinsic cognitive load of instructional materials should be initially be artificially reduced. This can be achieved by eliminating the interactions between elements and introduce isolated-interacting elements in subsequent learning phases. However, for experienced learners who already possess sophisticated schemas, the advantages of this method vanished.

The approach to manipulate intrinsic cognitive load is rather new. Nevertheless, future research on cognitive load will surely be influenced by this approach, since the manipulation of intrinsic cognitive load provides an effective measure for the external management of cognitive load.

Cognitive load theory provides great insights in our ability to learn and process information. However, it is far from a comprehensive framework that can fully explain human cognitive capabilities. Other cognitive perspectives also need to be taken into account to help us understand the potentials and limitations of human cognition so that we can design instructions accordingly. For instance, dual-coding theory, proposed by Paivio (1986), has been frequently studied and applied to computer-based multimedia instructions. Similar to cognitive load theory, dual-code theory is also based on cognitive information processing theory.

Dual coding Theory

The dual coding theory assumes that there are two cognitive subsystems. One of them specialized for dealing with language, while the other specialized for the representation and processing of nonverbal (visual) information. Paivio (1986) stated:

> Human cognition is unique in that it has become specialized for dealing simultaneously with language and with nonverbal objects and events. Moreover, the language system is peculiar in that it deals directly with linguistic input and output (in the form of speech or writing) while at the same time serving a

> symbolic function with respect to nonverbal objects, events, and behaviors. Any representational theory must accommodate this dual functionality. (p 53)

According to Paivio, the verbal system deals with language specific representations that include auditory, visual, and writing patterns of words. On the other hand, the nonverbal system (imagery) deals with the analysis of scenes and the generation of mental images (Paivio, 1986).

The two systems (verbal and nonverbal) are assumed to be distinct both structurally and functionally (Ryu, Lai, & Colaric, 2000). Structurally, they differ in the nature of representational units as well as the units organized into higher order structures. Functionally, they are independent since each system can be active without activation of the other one, or they can both be active in parallel. However, these two systems are also functionally interconnected. It allows the activity in one system to initiate activity in the other, or activities to be initiated in both systems.

Three different levels of processing can occur within or between the verbal and nonverbal systems, namely representational, referential, and associative (Paivio, 1991). *Representational processing* refers to the direct activation of a particular type of memory code by the corresponding type of stimulus. For instance, the word "dog" activates the verbal memory code, while a picture of a dog activates the visual system. *Referential processing* refers to the cross-activation of the two types of memory codes. Based on the above example, the word "dog" activates the corresponding imagen (hypothetical representational unit of visual system) in the nonverbal system, and the picture of a dog activates the related logogen (hypothetical representational unit of verbal system) in the verbal system. However, the relationships between the two systems are not always one-to-one. *Associative processing*, therefore, refers to activation of additional information within either system. For instance, sometimes, an image has the potential of recall many different verbal logogens.

Dual coding theory has been studied and applied to various learning situations. The most important contribution of dual coding theory to the field of instructional technology is the assumption of representational and referential processing in problem solving. Mayer and Anderson (1991) conducted several studies on dual coding hypothesis using animation and narrations. Result showed that students who were presented with animation and narration at the same time significantly outperform students who were presented with animation only, narration only, or no training on a measure of creative problem solving. Furthermore, the results also showed that presenting verbal and visual explanations without connecting them is much less helpful than coordinating verbal narration and animation simultaneously. The researchers stated that the finding is consistent with dual coding theory's assumption of representational and referential connection. Students who were presented with both verbal and visual information simultaneously have more opportunities to build referential connections than students in other condition groups. This concurrent presentation promotes referential connections and in turn facilitates problem solving. Mayer and Sims (1994) yielded similar results. However, they also found that inexperienced students were better able to transfer learning when visual and verbal explanations were presented simultaneously than when they were presented separately, while experienced learners do not benefit from visual aids with text format since they are already capable of retrieving appropriate knowledge from long-term memory as they read or listen. They can build connections between the verbal system and their internal systems.

Dual coding theory helps us fill in some gaps in the cognitive load theory. For example, dual coding theory supports the split attention effect in cognitive load theory and agrees that integration of verbal and visual presentation is more effective than separate presentation of the information. However, it questions the redundancy effect in CLT. According to dual coding theory, verbal text information, while presented with corresponding visual information, provides learners with greater opportunities to notice patterns and connections across or among these knowledge representations that can lead to a better integrated mental model or deeper understanding of the subject matter (Mayer & Anderson, 1997). In other words, if we try to reduce cognitive loads by providing learners with visual only, verbal only, or sequential verbal and visual information, learners may not have the opportunities to build the necessary referential connections needed for problem solving. This is especially true to novice learners (Mayer & Sims, 1994). Thus, both cognitive load theory and dual coding theory need to be taken into account when we design instructions or multimedia learning environments. Mayer (1997) further proposed a cognitive theory of multimedia learning that is derived from CLT, DCT, and several other learning theories.

Towards A Cognitive Theory of Multimedia Learning

Computer-based instruction has become popular since the past decade. New technologies make available new presentation formats such as animation, narration, and cueing. Computer-based multimedia instructional materials have been widely used in K-12 education as well as higher education settings. However, all too often, computer-based multimedia environments are rather cluttered and poorly designed. Learners in the multimedia environments tend to experience cognitive overload when dealing with multiple information representations (Paas, Renkl, & Sweller, 2003). Mayer (1997) reviewed 24 research studies on multimedia learning and proposed a generative cognitive theory of multimedia learning based on dual coding theory, cognitive load theory, model of working memory (Baddeley, 1992), generative theory (Wittrock, 1989), and Mayer's (1996) SOI (S = selecting relevant information, O = organizing information in a meaningful way to the learner, I = integrating the new information with the learner's prior knowledge) model of meaningful learning.

According to Mayer's multimedia learning theory, the learner possesses a visual information processing system and a verbal information processing system (Mayer, 1997). These two systems are used to explain learner's cognitive process in multimedia learning. Mayer and Moreno (2002) argued that learners engage in three important cognitive processes in multimedia learning. The first cognitive process is *Selecting*. Verbal and visual information serve as signals that help learners select relevant information. The second cognitive process is *Organizing*. Both visual and verbal information serves as organizers that help learners build cause-and-effect relations among pieces of visual information and among pieces of verbal information. The final cognitive process is *Integrating*. Learners build connections between corresponding parts in the visual representation and verbal representation. This cognitive model is illustrated in the following (Figure 1).

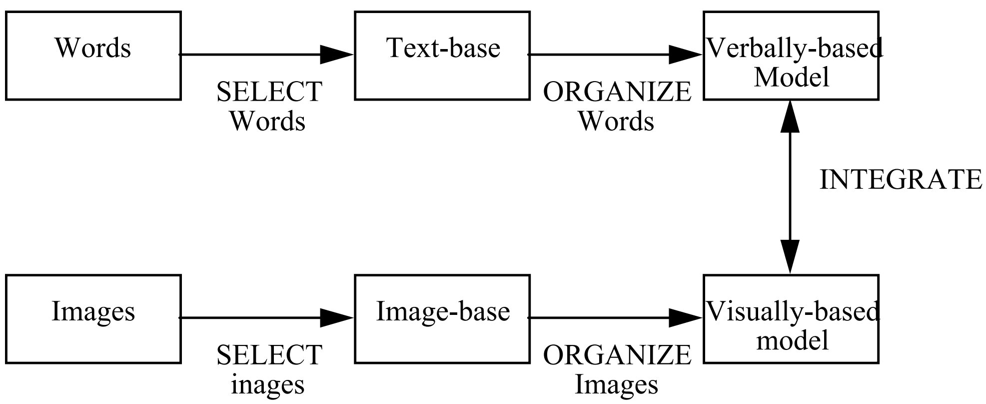


Figure 1. A cognitive model of multimedia learning (from Mayer, 1999)

Based on this cognitive model, Mayer and Moreno (2002) further recommended five principles on the design of multimedia learning. 1) The multiple presentation principle suggests that it is better to use two modes of representation (visual and verbal) rather than one. 2) The contiguity principle recommends that students learn more deeply if they do not have to hold the entire animation in working memory until the narration is presented, or vice versa. Corresponding words and pictures need to be presented contiguously. 3) The split-attention principle suggests that words is better presented as auditory narration rather than on-screen text. 4) The individual differences principle suggests that multimedia effect, contiguity effects, and split-attention effects depend on individual differences. Learners who lack prior knowledge tend to benefit more (Mayer & Sims, 1994). 5) Finally, the coherence principle proposes that students learn better if they do not have to process extraneous words and sounds in verbal working memory or extra pictures in visual working memory. Sweller and his colleagues refer to this as redundancy effect (Sweller et al., 1998).

The above discussion shows the beginning of a multimedia learning theory. All of the principles and assumptions are subject of further testing. Additionally, this theory only investigated limited aspects of multimedia learning environment. For example, most computer-based multimedia learning environments do not only have multimedia components, but also incorporate problem-based learning scenarios. This will further affect learner's cognitive load and learning process. Moreover, cognitive developmental theory is not considered in this multimedia learning theory and needs to be incorporated.

In conclusion, Mayer and his colleagues' research on multimedia learning provides valid empirical evidences that cognitive load theory and dual coding theory need to be carefully considered while designing multimedia learning environments.

More research needs to be done to investigate how these theories can be applied to multimedia learning environments to optimize learning.

So far, we have discussed several cognitive learning theories and their application to learning. In the next section, I would like to shift our attention to cognitive skills and their acquisition.

COGNITIVE SKILLS AND THEIR ACQUISITION

Defining Cognitive Skills

To define cognitive skills, we need to first understand "thinking". A typical dictionary definition of thinking is "Think…To have or formulate in the mind… To reason about, to reflect on, to ponder…" (American Heritage Dictionary, Second College Edition, 1982). Ericsson and Hastie (1994) defined thinking as "a sequence of internal symbolic activities that leads to novel, productive ideas or conclusions". Skills that are required to perform "thinking" can be defined as cognitive skills. In other words, skills needed to perform a sequence of internal symbolic activities are cognitive skills. According to major theories about thinking (Ericsson & Hastie, 1994), acquired knowledge and skills are the major variable that accounts for the largest individual differences in performance. Thus, acquisition of cognitive skills is an important variable that contributes to learning.

Bloom's Taxonomy

It is widely accepted that cognitive skills can be categorized into lower-order cognitive/thinking skills and higher-order cognitive/thinking skills. Bloom's (1956) taxonomy of thinking, one of the most well-known and quite popular among educators, categorizes the cognitive processes involved in learning into six major classes: knowledge, comprehension, application, analysis, synthesis, and evaluation. The six classes are also arranged in hierarchical order and represent the continuum from lower-order thinking/cognitive skills to higher-order thinking/cognitive skills.

Knowledge

Bloom et al. (1956) defined knowledge as the remembering or recalling of appropriate, previously learned information. To further classify knowledge objectives, knowledge is divided into two categories: knowledge of specifics and knowledge of universals. Knowledge of specifics refers to the type of knowledge that can be isolated and remembered separately, while knowledge of universals highlights the interrelations, through which information can be organized and structured and thus remembered.

Knowledge is the prerequisite and represents the basic level of educational objectives and cognitive skills. Remembering is the major cognitive process involved at this level. In the other levels, remembering is only one part of the more complicated cognitive process.

Comprehension

Comprehension refers to the understanding of the meaning of informational materials. There are three types of comprehension behavior: translation, interpretation, and extrapolation (Bloom et al., 1956). Translation means that individuals can put information into other terms or forms of communication. For example, to state the problem in one's own worlds is a type of translation. Interpretation involves dealing with certain information as a configuration of ideas, which requires reorganizing ideas into a new configuration so that the information can be comprehended. For example, generalization and summarizations are types of interpretation. Finally, extrapolation refers to the making of estimates or predictions based on the understanding of the materials. For instance, the making of inferences based on implications from the materials is a type of extrapolation.

Comprehension is at the second level of the cognitive domain of Bloom's taxonomy. It is probably the most emphasized class of intellectual abilities and skills in schools as well as colleges. Students are expected to understand what is being communicated in schools and to be able to make use of the ideas in it.

Application

Application indicates the intellectual abilities and skills required to solve problems by applying acquired knowledge, facts, techniques and rules in various ways. Comprehension is the prerequisite of application. Application requires comprehension of the materials, principles, methods, and theories (Bloom et al., 1956). However, application also differs from comprehension in that students can not only use the abstraction correctly when specifically asked to do so, but also use the abstraction correctly given an appropriate situation where no hints of solution is specified.

Generally speaking, application requires students to use previously learned information in new and concrete situations to solve problems that have single or best answers.

Analysis

Analysis emphasizes "the breakdown of the material into its constituent parts and detection of the relationships of the parts and of the way they are organized" (Bloom et al., 1956, p. 144). There are three levels of analysis. At the first level, learners break down the information into constituent parts and identify the elements. At the second level, learners need to find out the relationships among different elements and determine their connections. At the final level, learners have to recognize the structure and organizational principles of the information as a whole.

Analysis skills can be found frequently as objectives of any field of study. Teachers of science and social studies tend to specify analysis skills as one of their important objectives.

Synthesis

Synthesis can be defined as putting parts together to form a whole, with emphasis on creating a new meaning or structure (Bloom et al., 1956). It generally involves combining parts of the previous experience with new materials, and re-construct them into a new integrated whole. Comprehension, application, and analysis all involve putting together elements and constructing meaning. However, they tend to be more partial combination and construction than synthesis. Therefore, synthesis is at a higher level of cognitive domain than comprehension, application, and analysis. In addition, synthesis is the level in the cognitive domain which provides for most of the creative behavior on the part of the learner.

Evaluation

Evaluation is defined as the making of judgments about the value of ideas or materials (Bloom et al., 1956). It typically involves the use of criteria and standards for judging the extent to which the ideas/materials are accurate, effective, and satisfying. This judgment can be quantitative or qualitative, and the criteria can be either internal (from learners) or external (given to learners).

Evaluation is at the end of the cognitive process in Bloom's taxonomy. To some extent, evaluation requires behaviors and skills from all the preceding categories. However, the placement of evaluation in the taxonomy does not mean that it is the last step in thinking or problem solving. In fact, very often, evaluation will intrigue new attempts at comprehension or application and start a new around of analysis. Thus, the six cognitive domains should be viewed as an interrelated cycle rather than sequential steps in cognitive process.

Bloom et al. (1956) also specified key words associated with each cognitive domain. The key words used and the type of questions asked may aid in the establishment and encouragement of critical thinking, especially in the higher levels. The key words and the related categories are listed in the following table (Table 2.3).

Table 2.3 Key Words (Verbs) for the Six Major Cognitive Domains

Cognitive Domain	**Key Words (Verbs)**
Knowledge	defines, describes, identifies, knows, labels, lists, matches, names, outlines, recalls, recognizes, reproduces, selects, states.
Comprehension	comprehends, converts, defends, distinguishes, estimates, explains, extends, generalizes, gives examples, infers, interprets, paraphrases, predicts, rewrites, summarizes, translates.
Application	applies, changes, computes, constructs, demonstrates, discovers, manipulates, modifies, operates, predicts, prepares, produces, relates, shows, solves, uses.
Analysis	analyzes, breaks down, compares, contrasts, diagrams, deconstructs, differentiates, discriminates, distinguishes, identifies, illustrates, infers, outlines, relates, selects, separates.
Synthesis	categorizes, combines, compiles, composes, creates, devises, designs, explains, generates, modifies, organizes, plans, rearranges, reconstructs, relates, reorganizes, revises, rewrites, summarizes, tells, writes.
Evaluation	appraises, compares, concludes, contrasts, criticizes, critiques, defends, describes, discriminates, evaluates, explains, interprets, justifies, relates, summarizes, supports.

However, as education changed, as practitioners in different fields used this taxonomy, and as new knowledge emerged, it becomes increasingly clear that this taxonomy needs to be modified to better serve the needs of educators, especially teachers (Anderson & Krathwohl, 2001). As Bloom stated in a memorandum circa,

> "Ideally each major field should have its own taxonomy of objectives in its own language-more detailed, closer to the special language and thinking of its experts, reflecting its own appropriate sub-divisions and levels of education, with possible new categories, combinations of categories and omitting categories as appropriate." (1971)

A New Taxonomy for Learning, Teaching, and Assessing

Anderson and Krathwohl (2001), together with other editors, modified Bloom's taxonomy and proposed a new taxonomy framework. However, since this taxonomy is still new, its impact on education remains to be seen and investigated. In the following section, I'll briefly discuss the components of the new taxonomy as well as how it differs from Bloom's original taxonomy.

Components of the New Taxonomy

The new framework has two dimensions: knowledge dimension and cognitive process dimension. Therefore, the new taxonomy is represented in a table format and is referred to as the Taxonomy Table. The rows and columns of the table contain categories of the knowledge and cognitive process dimensions respectively (see Table 4). The cells of the table, consequently, are where the knowledge and cognitive process dimension intersect.

Table 4 The Taxonomy Table

The Knowledge Dimension	**The Cognitive Process Dimension**					
	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A. Factual Knowledge						
B. Conceptual Knowledge						
C. Procedural Knowledge						
D. Meta-cognitive Knowledge						

From Anderson & Krathwohl (2001)

The Knowledge Dimension

Anderson and Krathwohl (2001) defined four general types of knowledge: factual, conceptual, procedural, and metacognitive.

Factual knowledge refers to knowledge of separate, isolated content elements. For example, knowledge of terminology or specific details is factual knowledge. *Conceptual knowledge*, on the contrary, is knowledge of more complex and organized forms. Knowledge of principles, categories, theories, model, and structure are all conceptual knowledge. *Procedure knowledge*, as we can see literally, means the knowledge of how to do something. For example, knowledge of skills, techniques, methods, or criteria used to make justification can all be referred to as procedural knowledge. Finally, *Metacognitive knowledge* is "knowledge about cognition in general as well as awareness of and knowledge about one's own cognition" (Anderson & Krathwohl, 2001, p. 55). It includes strategic knowledge, knowledge of cognitive tasks, self-knowledge, and so forth.

The Cognitive Process Dimension

The purpose of this dimension is to provide a comprehensive set of classifications for learners' cognitive processes that are commonly included in educational objectives. There are six major categories, namely remember, understand, apply, analyze, evaluate, and create. Each of those categories is associated with two or more specific cognitive processes, with a total of 19 different cognitive processes.

Remember is one of the most commonly stated retention-based educational objectives. It is essential for meaningful learning and problem solving. *Remember* simply involves two cognitive processes: recognizing and recalling (Anderson & Krathwohl, 2001). To recognize, learners need to retrieve relevant information from their long-term memory to compare it with the incoming information. An alternative term for recognizing is identifying. To recall, learners need to retrieve information from long-term memory when they were asked to do so. Recalling can also be called retrieving.

Understand is the largest category of transfer-based educational objectives. It includes seven types of cognitive processes, namely interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining (Anderson & Krathwohl, 2001). 1) Interpreting requires learners to convert information from one representational form to another. Alternative terms for interpreting includes translating, paraphrasing, representing, and clarifying. 2) Exemplifying involves learners identifying features of a general concept or principle and using those features to construct a specific example. It can also be called illustrating and instantiating. 3) Classifying occurs when learners recognize relevant features or patterns that belong to a specific instance, concept, or category. It is equivalent to categorizing or subsuming. 4) Summarizing involves constructing a shortened abstract representation of the information. Alternative terms for summarizing are generalizing and abstracting. 5) Inferring involves detecting patterns or relationships within a series of examples of instances. Verbs such as extrapolating, interpolating, predicting, and concluding can also be used to refer to inferring. 6) Comparing requires learners to detecting similarities and differences among objects, events, ideas, problems, and so forth. Alternative terms for comparing are contrasting, matching, and mapping. 7) The final type of cognitive process in this category is explaining. It involves constructing a cause-and-effect model, including each major part of the system, and using the model to determining how changes in one part affects changes in another part. An alternative term for explaining is constructing a model.

Apply is closely connected with procedural knowledge, because it involves using procedures to perform tasks or solve problems. It is a very important educational objective for meaningful learning in authentic context. This category includes two cognitive processes: executing and implementing (Anderson & Krathwohl, 2001). In executing, learners carry out a procedure when encountered with a rather familiar exercise or task. It is often associated with the use of skills and algorithms. Alternative term is carrying out. In implementing, learners select and use certain procedures to perform tasks that are usually unfamiliar. In order to implement, learners need to understand the problem encountered and modify the known procedures to "fit" the problem. Thus, implementing is sometimes used together with other cognitive process categories such as Understand and Create.

Analyze requires learners break materials into parts and determine the relationships among different parts as well as the overall structure. This category includes three cognitive processes: differentiating, organizing, and attributing (Anderson & Krathwohl, 2001). In differentiating, learners need to distinguish the parts of a whole structure in terms of their relevance or importance. It often occurs when learners discriminate relevant/important from irrelevant/unimportant information. Alternative terms for differentiating are discriminating, selecting, distinguishing, and focusing. In organizing, learners build systematic and coherent connections among pieces of information. It involves identifying elements of the presented information and recognizing how they work together to build an integral structure. Alternative terms for organizing are structuring, integrating, finding coherence, outlining, and parsing. The final cognitive process in this category is attributing. It involves deconstructing, in which learners determine the underlying intention of the presented material. Thus, it extends beyond the basic understanding to surmise the intention underlying the presented information. An alternative term for attributing is deconstructing.

Evaluate is making judgments based on certain criteria or standards. This category includes two cognitive processes: checking and critiquing (Anderson & Krathwohl, 2001). In checking, learners test for internal inconsistencies or fallacies in a product or operation. In a problem-solving environment, checking involves determine whether the problem-solving plan is working. Alternative terms for checking are testing, detecting, monitoring, and coordinating. In critiquing, learners judge a product or operation based on external criteria and standards. It is essential to critical thinking. In a problem-solving environment, checking involves judging the merits of a particular problem solution (e.g. the advantages and disadvantages of relocating an endangered specie to a certain environment). An alternative term for critiquing is judging.

The final cognitive process category is *Create*. *Create* involves putting elements together to form a new coherent and functional whole. Unlike all of the above categories, *Create* involves the construction an original product. However, educational objectives for *Create* do not often require creativity. Rather, they call for unique production. *Create* is associated with three cognitive processes: generating, planning, and producing (Anderson & Krathwohl, 2001). Generating is also called hypothesizing.

It involves representing the problem and arriving at hypothesis or alternatives that meet certain criteria. Generating involves divergent thinking and is a critical process for creative thinking. The second cognitive process in this category is planning. Planning involves developing a plan for problem-solving. In planning, learners need to establish subgoals and list subtasks to be performed to solve the problem. An alternative term for planning is designing. The final cognitive process is producing. In producing, learners carry out a plan for solving a given problem. It occurs when learners were asked to create a product that corresponds to certain specifications.

From the above discussion, we can see that there are some overlaps between the new and the original taxonomy. However, the structures of the two taxonomies are quite different. I'll then summarize some of the major changes in the new framework and how it differs from the old one.

Major Changes in the New Taxonomy

The most important change in the new taxonomy is the change in structure. The new taxonomy separates the noun and verb components embedded in the original *Knowledge* category. The noun aspect of *Knowledge* becomes a new dimension with four categories: factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge. The verb aspect of *Knowledge* becomes the new *Remember* category. Since knowledge becomes a new dimension, Anderson and Krathwohl (2001) decided to create a two-dimensional taxonomy table with knowledge as the row category and cognitive process as the column category. Thus, the cells of the table show the interactions between the two dimensions and contain the educational objectives. This innovative two-dimensional structure allows teachers to analyze instructional objectives, activities, and assessment tasks. The taxonomy table is a more precise representation of educational objectives than the original taxonomy. Additionally, the six new categories in the cognitive process dimension also differ from the original taxonomy in that the new categories are ordered in terms of increasing complexity, while the original categories were organized into a cumulative hierarchy. In other words, in the original taxonomy, the mastery of a more advanced category requires mastery of all the categories below it. For example, to master skills in the *Comprehension* category, learners need to master all the skills in the *Knowledge* category. However, in the new taxonomy, this hierarchy is not cumulative in nature.

Changes in structure require corresponding terminology changes. Consequently, another major change in the new framework is the terminology (Anderson & Krathwohl, 2001). In Bloom's taxonomy, all six categories are nouns, whereas they take the verb form when used in objectives. This does not truly reflect components of educational objectives, which usually indicate that the students should be able to do something (verb) to/with something (noun). The new taxonomy, however, has two dimensions: knowledge and cognitive process. The categories in Knowledge dimension are nouns, and the categories in Cognitive Process dimension are verbs. This change in structure and terminology reflects the verb-noun relationship in educational objectives.

This major change in structure and terminology, ultimately, reflects the change of focus in the new taxonomy. Bloom's taxonomy focused mainly on assessment, whereas the revised taxonomy emphasizes the use of the framework not only in assessment, but also in curriculum planning, and instruction. Additionally, the original taxonomy aimed at higher education, while the revised version emphasizes teachers at all grade levels. And finally, the original framework focused on the six major categories, while the new taxonomy focuses on subcategories and offers a more detailed description of the subcategories.

Both Bloom's taxonomy and the revised taxonomy offer valuable insights in the range of cognitive processes involved in learning as well as the type of cognitive skills associated with them. With their taxonomy of cognitive processes in mind, we are now ready to discuss the acquisition of cognitive skills.

Acquisition of Cognitive Skills

As we mentioned in the previous section, cognitive skills are concerned with analysis, interpretation, problem solving, evaluating, decision making, and so forth. Therefore, the development and acquisition of cognitive skills is an important goal for education. There are many theoretical and empirical studies in the field of cognitive skills development. However, the findings are usually inconclusive and sometimes even confusing (Liu, 2003). As VanLehn (1996) pointed out, there is no existing model of skill acquisition that can account for the acquisition of various cognitive skills. Nevertheless, there is a generally accepted process for cognitive skill acquisition that is based on Fitts' (1964) three phases for motor skill acquisition. The categorization of early, intermediate, and late phases aptly describes the course of cognitive skill acquisition (VanLehn, 1996).

In the early phase, learners are trying to understand the domain knowledge without yet trying to apply it. This stage is often dominated by reading, discussing, and other information-acquiring activities. Since this early stage is more like a preparation stage for skill acquisition, most studies do not collect data during this phase (VanLehn, 1996).

In the intermediate phase, learners turn attention to solving problems, typically after studying a few problems that have already been solved. In this phase, learners remove misconceptions and fill the gaps in knowledge arising from missing knowledge. Ultimately, they remove all the flaws in their knowledge and can solve problems without conceptual errors. This signals the end of the intermediate phase.

In the late phase, learners continue to improve in accuracy and speed through practice. They become more efficient in application of the acquired skills; however, their basic approach to solve the problems does not change significantly in this phase.

Obviously, this three-phase distinction is an idealization, because the boundaries between each phase are not clear and sharply defined. However, this categorization is helpful for us to understand how cognitive skills are developed and acquired by learners.

Cognitive Skills Acquisition in Computer-Based Learning Environments

During the past few years, computer-based interactive learning environments have become popular in American schools. Consequently, researchers start to investigate the effect of such learning environments on students' cognitive skill acquisition.

Liu (2003) investigated how to design interactive multimedia learning environments to provide essential support for acquiring higher level cognitive skills. She took an innovative learn-by-design approach towards multimedia education and synthesized a number of studies conducted over the past few years on the effect of such learning environment on cognitive skill acquisition for elementary school, middle school, and high school students. To examine the cognitive skills, both quantitative and qualitative measures are used in those studies such as project design questionnaire, design task ranking, performance assessment, concept maps, resource management strategy questionnaire, interviews, observations, and response logs. Results of the studies under examination showed that at high school level, learners internalized several important design (cognitive) skills and their understanding was significantly increased for planning, searching information, connecting ideas, importance of audience, and collaboration. At the middle school level, learners understood the different steps involved in creating a multimedia product, and also realized the significance of planning, designing, and testing (Liu & Hsiao, 2002). And at the elementary school level, learners in the designer group had a significantly better understanding of the importance of planning and collaboration than learners in the non-designer group. These findings suggest that learner-as-multimedia-designer environment have positive effect on students' motivation, encourage creativity, and enhance the acquisition of higher-level cognitive skills. Liu (2003) further identified four key factors in the design of multimedia learning environment to support acquisition of cognitive skills. 1) learning environment has to be authentic; 2) project-based learning environment emphasizes on the product and the process, which allows students to develop cognitive skills "just-in-time"; 3) the cognitive skills need to be discussed explicitly, and practice continuously; 4) scaffolding is essential to support the development of higher level cognitive skills.

Liu's studies focused on how the learn-by-design approach and the design process support learners' cognitive skills acquisition. However, there are many different approaches to create interactive computer-based learning environments. For example, Ross and Bolton (2002) took a problem solving approach and used worked examples as the major component of a computer-based learning environment for Physics. They described various protocols for solving physics problems, and further discussed the usefulness of their framework on helping students develop appropriate strategies for problem representations, select targets, plan solutions, and check answers. Eventually, the learning environment should help students acquire higher level skills of quantitative problem-solving. Nevertheless, they did not have any empirical evidence to support their hypothesis. Formal research needs to be done to investigate the effect of their learning environment on learners' cognitive skills acquisition.

Instead of focusing on the entire learning environment, some researchers chose to narrow down their investigation on specific cognitive tools that are built in the environment. Sleight (2003) examined the effect of paper-based support tools to help learners acquire complex cognitive skills. The tools under investigation in her study were assignment form, criterion checklist, prime example of the assignment, and annotations to the example and checklist. An observational case study design was used to conduct the study. Observation data and video data were collected and analyzed. The results showed that all of the four learners made extensive use of the tools. Except individual differences in tool use, all learners used the tools for self-explanation, motivation, and resolution of conceptual conflict. The tools support learners' decision making, and prevent, detect, and correct errors in the performance of complex cognitive tasks. Thus, the researcher concluded that these tools provided an effective way to support learners in acquiring complex cognitive skills. However, the tools investigated in this study are paper-based. Although the researcher described comparable computer-based support tools, further research is needed to investigate how the computer version of those tools support learners' cognitive skill acquisition. Chung, Severance, and Chung (2003) also gained promising results on the use of computer-based support tools to support cognitive skills acquisition. The tools they investigated were prompts that were used to support three activities: summarizing, explaining, and reflecting. The results showed that students who used support tools generated more ideas and integrated them in their report writing more. In addition, they engaged in more convergent knowledge building and integrated more concepts and examples.

In conclusion, research base for cognitive skills acquisition in computer-based learning environments is still rather limited. More research is needed to search for ways in designing effective computer-based learning environments as well as computer-based cognitive tools to support higher-level cognitive skills acquisition.

To this point, our discussion on cognitive developmental theory, cognitive load theory, dual-coding theory, and cognitive skills acquisition all call for the design of cognitive tools to share learners' cognitive load, support their cognitive processes, and facilitate cognitive skills acquisition. In the final section of my literature review, I will focus on cognitive tools and how they can be designed to support learning.

COMPUTER-BASED COGNITIVE TOOLS

What are cognitive tools?

Lajoie (1993) viewed cognitive *tools* as any tools that can assist learners in accomplishing cognitive tasks. She identified four types of cognitive tools by the functions they serve:

(a) support cognitive processes, such as, memory and metacognitive processes;

(b) share the cognitive load by providing support for lower level cognitive skills so that resources are left over for higher order thinking skills;

(c) allow the learners to engage in cognitive activities that would be out of their reach otherwise;

(d) allow learners to generate and test hypotheses in the context of problem solving. (p. 261)

Jonassen and Reeves (1996) further defined *cognitive tools* as any tools that "enhance the cognitive powers of learners during thinking, problem-solving, and learning" (p. 693). For example, semantic networks are cognitive tools that engage learners in the reorganization of knowledge, deep processing of knowledge, and relating new knowledge to one's existing knowledge. Jonassen and Reeves discussed examples of recognized computer-based cognitive tools that function as intellectual partners to facilitate learners' critical thinking and higher-order learning, such as databases, spreadsheets, semantic networks, expert systems, multimedia/hypermedia construction software, computer-based conferencing, collaborative knowledge construction environments, computer programming languages, and microworlds. However, they also emphasized that computer-based cognitive tools are not limited to what they have discussed.

According to Jonassen (1992), those computer-based cognitive tools share a common set of attributes:

> …They are readily available, generic applications; they are affordable; they are used to represent knowledge in content domains; they engage critical thinking in learners; they facilitate transfer of learning; they are simple, powerful formalisms; and they are reasonably easy to learn (p. 702).

Theoretical foundation for computer-based cognitive tools

Constructivism

Constructivists view learning as a constructive process through which the learners are building their own representations of knowledge. And this representation is constantly open to change. Thus, learning is an active process through which meaning is developed on the basis of experience. As Bruner (1960) stated, learning is an active process in which learners construct new ideas or concepts based upon their current/past knowledge. The learner selects and transforms information, constructs hypotheses, and makes decisions, relying on a cognitive structure to do so. Cognitive structure (i.e., schema, mental models) provides meaning and organization to experiences and allows the individual to go beyond the information given. In addition, since knowledge is constructed by each individual, it will be unique. Therefore, no two people will possess the same prior knowledge and will construct the exact same understanding. Learners will construct his or her own interpretation of the knowledge being acquired (Jonassen, Mayes, & McAleese, 1993a).

Constructivists are constantly searching for an optimal context for learning and knowledge construction. They are particularly interested in creating learning environments in which learners can be actively involved. This environment should help learners construct their own knowledge, instead of having teachers tell them what their interpretations of the world should be. The advancement of computer technology makes the development of such learning environments a possibility. A wide range of computer-based constructivist learning programs has been built on almost all subject areas and all grade levels.

In a constructivist environment, learners can make use of cognitive tools to support the construction of their own knowledge representations. Cognitive tools, due to their specific features, can help learners organize information, restructure schemata, and represent their knowledge. Cognitive tools can activate complex critical thinking and high-level information processing. They can engage learners in constructing knowledge, which reflects their own interpretations and conceptualizations of reality. Thus, learners are required to think harder and generate more thoughts. For example, databases, as cognitive tools, require learners to identify the information needed, develop a data structure, locate the relevant information, and create queries. This process engages learners in important thinking skills such as analyzing, evaluating, organizing, connecting, decision-making, and problem solving (Jonassen & Reeves, 1996).

Learning with Technology

Computers and related technologies sometimes are viewed as tools to support learning, in which the computer is playing a rather passive role that could be replaced with other tools such as pencil and paper (Collins, 1984). Or, computers are considered to be instructional communications that function as media or resources for learners (Newman, 1988). These viewpoints are flawed in that they regard technologies as merely delivery media that students learn *from*. In other words, they only focus on what technology can do to the learner or the effects *of* technology. An important aspect, which pertains to what the learner can do *with* the technology, has been omitted. In this aspect, the concern is "…what a computer enables the individual to do while working, planning, writing, designing, or communicating with computer software" (Salomon, 1990, p. 30). The learner's role is more like an intellectual partner of the computer who interacts with it. And in turn, the computer program offers an intellectual partnership that transcends the limitations of human cognition, such as limitations to memory, thinking, or problem solving (Pea, 1985).

Computer-based cognitive tools are important to this way of conceptualizing relationships between users and computers. Salomon, Perkins and Globerson (1991) suggested that "cognitive effects with computer tools greatly depend on the mindful engagement of learners in the task afforded by these tools and that there is the possibility of qualitatively upgrading the performance of the joint system of learner plus technology" (p. 2). In order to learn with technologies instead of being controlled by them, learners should be empowered with cognitive tools so as to access and enhance their abilities in conjunction with the use of these tools.

Distributed cognitive processing

One of the greatest advantages of computer-based cognitive tools is to distribute cognitive processing. Since we know that there are certain aspects of cognitive processing that we as human beings do best and other aspects of cognitive processing that technologies do best, computer-based cognitive tools should be designed so that "learners should be responsible for recognizing and judging patterns of information and then organizing it, while the computer should perform calculations, store information, and retrieve it on the learner's command" (Jonassen & Reeves, 1996, p. 697-698). As a result, learners are engaged in more meaningful cognitive processing, instead of reproductive processing. For example, a note-taking tool can provide learners with a way to store all the important information needed for problem-solving without memorization. Therefore, lower level cognitive tasks are distributed to the computer-based cognitive tools, while learners are freed to focus on higher level cognitive tasks, which contribute to learning.

Computer-based cognitive tools to support learning

As we discussed above, *cognitive tools* refer to any tools that support aspects of learners' cognitive processes and enhance their cognitive powers. In the following section, I will review and discuss how computer-based cognitive tools are used to support learning and the construction of knowledge. *Table 2.5* highlights the cognitive tools discussed in this paper.

Table 2.5

Empirical Studies on Computer-Based Cognitive Tools

Cognitive Tools	Study	Findings
Database	Hartson (1993)	Students choose a bird to research for building a database. The project helped students develop the skills of classification, observation, record keeping, analysis, and interpretation of data; interdisciplinary connections, as well as communication.
	Norton & Harvey (1995)	Database activities need to involve students in four actions: searching, sorting, creating, and reporting. Searching and sorting are information gathering skills, while creating and reporting are knowledge building skills. The activity illustrated in the article structured database use in a way that students become knowledge builders.
	Pon (1984)	Databases as cognitive tools give students a way to manipulate the excess cognitive load, and provide students opportunities to create strategies for critical thinking.
	Watson & Strudler (1988-89)	Building a database is an analytical process that involved important critical-thinking skills such as analyzing, synthesizing, and evaluating information. However, without effective teaching strategies, instructional databases would not have a significant effect on students' higher order thinking skills.
Semantic Networking	Alpert & Grueneberg (2000)	Computer-based concept mapping tools can provide representational capabilities that allow students to express their knowledge more fully by incorporating dynamic media such as sound, video, and animation.
	Basque & Pudelko (2003)	Observations showed that student generally found the concept mapping helpful. However, the full potential of concept mapping as knowledge construction support tool was not optimized. More research needs to be done to identify the best conditions for using concept mapping to construct knowledge in distance learning context.
	Feghali (1991)	The use of computer-based semantic networks was an excellent platform to reveal the way students construct knowledge. However, a traditional achievement test could not reveal the cognitive outcomes of semantic network construction. Other dependant variables such as knowledge transfer would provide useful information.
	Jonassen (1993)	Cognitive structures of the learners in both treatment groups changed. Students using the semantic network cognitive tool possessed more hierarchical knowledge structures at the end of the course than the group using the expert system tools.

	Steketee, et. Al. (2001)	The group knowledge negotiation and construction process typically occurred when the concept mapping tool is present. It was inferred that concept mapping, as a cognitive tool, within the distributed learning environment contributed to effective learning.
Expert System	Lippert (1988)	The knowledge bases that students built showed that students had reviewed a great amount of information. Students mastered the content that they were originally not expected to master. Moreover, expert system had the potential to merge three roles, tutor, tutee, and tool, into a single system.
Computer Programming Language	Harel (1991)	No significant differences were found through quantitative methods. However, the general trend was rather positive in terms of specific learning outcomes as shown in tests, exercises, observations and interviews.
	Liao & Bright (1991)	a meta-analysis of research on the effects of computer programming on cognitive outcomes. The results showed that the majority of studies found that students who learned to program scored higher on various cognitive tests than those who did not. However, the difference was not large.
Spreadsheet	Abramovich, Stanton, & Baer (2003)	Demonstrated that multiple features of a Spreadsheet tool extended motivational activities and enhanced mathematical thinking of younger children in the context of data analysis and probability. High level of success in performance was observed.
	Dugdale (2001)	Reported that students used the Spreadsheet environment of dynamic exploration and visualization of mathematical relationships.
	Sutherland & Rojano (1993)	During the study, students used spreadsheets to represent and solve algebra problems. They moved from cause-effect local numerical notion of algebraic relationships to rule-governed relationships that were symbolized in spreadsheet.
Computer microworld Environments	Lajoie(1993)	Computer can be used as cognitive tools for learning, restructuring of knowledge, mental model building and promoting confidence in problem solving.
Hypermedia / Multi-media Authoring system	Lehrer(1993)	The hypermedia design approach led to richer, connected, and more applicable knowledge. Lehrer also pointed out that “the most striking finding was the degree of students’ involvement and engagement” Both high and low ability students were very task-oriented and gained increasingly more confidence with the hypermedia authoring tool.
	Liu & Hsiao (2002)	Learner-as-designer-environment facilitated the development of cognitive skills of middle school students, and engaged them in active learning. However, they are not cognitively ready to manage time and effort efficiently in multimedia authoring environment.

	Liu (1998a)	Multimedia authoring promoted elementary school students' motivation and facilitate their cognitive development. Students' creative thinking scores increased significantly in the measures of fluency, elaboration, and resistance to premature disclosure.
	Liu (1998b), Liu & Rutledge (1997)	Cognitive apprenticeship-based learner-as-multimedia-designer environment enhanced high-school students' motivation and learning of design knowledge. In addition, working with and design for a real client helped to bring about bigger changes in motivation and design skills.
Collaborative Knowledge Construction Environments	Greer et al. (2000) Peer Help System	Integrate several cognitive tools into a intelligent intranet peer help desk facility – a collaborative knowledge construction environment where students are able to explore the information, elaborate and explain their interpretation of the knowledge, compare their knowledge with that of the others', evaluate their own knowledge, and so on
	Knowledge Forum	Build a collaborative knowledge construction environment where learners can cooperate to build networks of ideas; construct, store, and retrieve information; construct their own knowledge; and so on
	Schank & Kozma (2002)	ChemSense, a knowledge construction environment, allows students to collaborate in the investigation of chemical phenomena, collect data, build representations of those phenomena, and participate in scaffolded discourse to explain the underlying principles. It facilitates students' chemical understanding and representational ability.
Combined cognitive tools use in classrooms	Reeves et al. (1997)	Statistically significant difference was found in "problem solving" between the group of students who used the cognitive tools and the two control classes. The use of computer-based cognitive tools in classrooms helps increase students' ability to frame and resolve ill-defined problems. Higher order learning outcomes can be achieved through the implementation of cognitive tools.
Pedagogical agents	Moreno, Mayer, and Lester (2000)	The use of pedagogical agent in a discovery learning environment promotes better meaningful learning. Students using a pedagogical agent also showed greater interest and motivation
	Moreno, Mayer, and Lester (2001)	This follow up study found that interactive pedagogical agents resulted in better retention and transfer. In addition, students are more actively involved in processing lesson materials.
Comprehensive Overview of Cognitive Tools	Jonassen & Reeves (1996), Jonassen, et al. (1998),)	General discussion of computer-based cognitive tools, their uses and related research. Tools discussed includes computer programming languages, multimedia/hypermedia construction software, microworlds, expert systems, semantic networks, spreadsheets, databases, conversation tools, and system modeling tools.

Database as Cognitive Tools

Database is a type of organizational tool that enables learners to analyze and organize information. A database consists of files, which contain a set of records. Each record is divided into fields based on the type of information to be contained. And the same type of information is stored in each field in each record. Database management systems allow users to store, manage, search, and sort information in the database. As applied to the educational context, students can analyze and enter relative information into databases, which can then be searched and sorted to answer specific questions and seek interrelationships within the information.

Databases can function as cognitive tools because of their organized and defined nature (Jonassen & Reeves, 1996). However, there are no formal research studies on the use of databases as cognitive tools. Only unreliable evidence exists to support the efficacy of databases. For example, Hartson (1993) reported a very successful use of databases in the Birds Project, which helped student develop the skills of classification, observation, record keeping, analysis, interpretation of data, interdisciplinary connections, as well as communication. Yet, there is no formal empirical research done to validate her observations. Hence, most of the evidence I discussed in this section come from classroom observations.

Rooze (1988-89) stated that the creation of databases allows students to find out what information to collect and how to organize those bits of information into meaningful categories. The creation of databases facilitates students' acquisition of information and the analysis of content domains through breaking down information into its essential parts and organizing it into related categories. Pon (1984) used database software as an inquiry tool to support higher-order thinking in a fourth-grade American Indian studies class. At first, she had students gather data on California Indians from the local library and Indian museum. Then, students were asked to design a form to display the data they collected, using labels to classify each piece of information. The form was entered into the computer database. The teacher also showed students how to make data searches to verify their generalizations about the tribes. Finally, students had group discussion on this specific study. She found out that most students were not cognitively ready to create and test hypotheses by making a database search. However, they did discuss why certain attributes were related. She also noticed that students thought more critically than she would expect, especially when they discussed the validity of their data

> Could it have been found with different wording? Even if the hypothesis was validated, did it really prove a cause and effect? Perhaps Indians who ate acorns used the mortar and pestle to wash clothes (Pon, 1984, p29).

She reported that database tools gave students a way to manipulate a large amount of information and provided them with opportunities to create critical thinking strategies.

Watson and Strudler (1988-89) used databases in a more complete way in a lesson that teaches higher-order thinking skills. Prior to the lesson to teach higher order thinking skills, students had lessons on basic database operations such as arranging records, planning reports, building data files, and so forth. Then, students began the lesson with pre-established data files. Earlier classroom activities focused on adding and retrieving information from the database, which involved lower order skills such as comprehension and application. Later classroom activities emphasized breaking down information to find relationships, organizing information, and making conclusions or judgment. These activities involved higher order thinking skills such as analyzing, synthesizing, and evaluating. They suggested that building a database is an analytic process that involved important critical-thinking skills such as analyzing, synthesizing, and evaluating information. However, they also mentioned that database only provided the medium for developing higher order thinking skills. Without effective teaching strategies, such as Taba's Inductive Thinking model they used in this lesson, instructional databases would not have a significant effect on students' higher order thinking skills. Norton and Harvey (1995) also made full use of the functionality of databases in their Donner Party lesson, which was inspired by an article in *Discover* Magazine titled "living through the Donner Party". They created a database using the information provided by the article. The database contains data on the Donner Party members such as age, gender, survivorship, etc. As the students confronted with questions, the researchers offered them the opportunity to use the database. The activities created around database use promoted four types of student actions: searching, sorting, creating, and reporting. Norton and Harvey pointed out that searching and sorting activities focus on information gathering skills, while creating and reporting focus on knowledge building skills. By challenging student to go through the entire cycle of information transformation – searching, sorting, creating, and reporting – the database use is structured to help students become knowledge builders instead of knowledge receivers.

The above discussion strongly suggests that constructing databases would improve students' ability to comprehend domain knowledge and inferences from information. However, there is certainly a lot to be done here for future research. We are in urgent need of empirical evidence on the use of databases as cognitive tools.

Semantic Networking as Cognitive Tools

Semantic networking tools provide visual tools for users to develop concept maps, a hierarchical representation of concepts that indicates the relationship among the concepts as understood by an individual.

Semantic networking can function as cognitive tool because it engages many cognitive skills such as reorganizing learners' knowledge, relating new concepts to existing concepts, and analyzing the structural relationship among the concepts (Davis, 1990). Feghali (1991) investigated the use of computer-based semantic network construction and how it affected the quality and quantity of students' specific knowledge structures. 37 out of 130 engineering college students, who enrolled in a C programming class, were randomly chosen to learn to use semantic network. Students learned semantic network concepts and constantly generated computer-based semantic networks based on the course content. A post-test was administered on students' achievement. Students also completed personal profile questionnaires and self-reports to reflect any individual differences. Although students who learned and built semantic networks scored better in the test than students who did not, no statistically significant results were found. It was concluded that the use of computer-based semantic networks was an excellent platform to reveal the way students construct knowledge. However, a traditional achievement test could not reveal the cognitive outcomes of semantic network construction. Other dependant variables such as knowledge transfer would provide useful information.

Semantic networks are representations of human knowledge structures. Jonassen (1993) compare semantic network with another cognitive tool called expert system. 31 students, who enrolled in two sections of the same course in an Instructional Technology program, participated in the study. Pre-test and post-test were administered using the instrument Pathfinder networks. This instrument required students to complete a pairwise rating of the relatedness of 23 concepts from the instructional content. It then generated a net of those concepts based on students' responses. After the pre-testing, students in the semantic network group were taught how to use a semantic networking tool, while students in the expert system network group were taught how to use an expert system tool. Students' pretest and posttest nets were compared based on the similarity of posttest to pretest nets, the comparison with expert's nets, and the comparison with a net that represented the causal strength of relations between each concept. The results showed that the cognitive structures of the learners in both treatment groups changed significantly towards the expert's cognitive structure. Although no statistically significant difference was found, the nets produced by the semantic network group were more hierarchically organized into more meaningful groups of related concepts. Jonassen (1987) also verified that the underlying structures in semantic networks were an accurate means for mapping individual's cognitive structure. Building semantic networks can change an individual's cognitive structure towards the expert's cognitive structure.

Another interesting study investigating the use of computer semantic network tool was done through action-research methodology. Steketee et al. (2001) wanted to find out whether computers as cognitive tools really enhance learning or not. Inspiration, an electronic concept-mapping tool was chosen because of the interrelated nature of the concepts and topic modules within the unit of instruction. Students worked in collaborative groups. Four of the groups were observed, and audio-taped as they constructed concept maps and completed class activities. Group dialogue was the focus of analysis. Social discourse, procedural discourse, prestructure discourse, foundational discourse, relational discourse, and metacognitive discourse were found evident in the transcripts. Overall, structural discourse had the strongest presence. And the group knowledge negotiation and construction process typically occurred when the concept mapping tool is present. It was inferred that concept mapping, as a cognitive tool, within the distributed learning environment contributed to effective learning.

Furthermore, due to the dramatic development of distance education programs, several recent studies investigated the use of concept mapping as cognitive tools in distance learning context. The findings generally support the use of concept mapping as cognitive tools to facilitate (collaborative) knowledge construction (Basque & Pudelko, 2003; Alpert & Grueneberg, 2000). However, they also pointed out that the full potential of concept mapping is not optimized. For example, with the advancement of technology, concept mapping tools can be extended to allow student to express their knowledge more fully by incorporating various media – sound, video, animation, and so forth (Alpert & Grueneberg, 2000).

To sum up, the use of semantic networks as cognitive tools is supported by a body of research. Constructing semantic networks help learners analyze their own knowledge structures and integrate new knowledge into existing knowledge structures. The process also changes an individual's cognitive structure towards the expert's cognitive structure.

Expert System as Cognitive Tools

An expert system is "a computer program that simulates the way human experts solve problems using a production rule (if-then) formalism" (Jonassen & Carr, 2000). It basically consists of a knowledge base that is entered into an expert system shell. It has the following components: a text editor for entering information; a machine representation that is constructed by the parser and verification routine to check for surface validity; and the inference engine that questions the users to determine whether a decision is valid or not. The expert system has traditionally been used as decision support systems for providing advice or help to novices, or as an intelligent tutoring system with expert models and a knowledge base of information to be tutored.

Most research studies on expert system focused on students as users of predefined production rule expert systems. More recently, the use of expert systems as computer-based cognitive tools has been investigated. Trollip and Lippert (1987) found that the development of expert systems involved deep analysis of the subject matter that learners finally developed a greater comprehension of the subject matter. They concluded that building expert rule bases engaged learners in analytical reasoning, synthesis, and metacognition. According to Jonassen, Wilson, Wang, and Grabinger (1993), building expert systems as cognitive tools required learners to identify declarative knowledge (facts or concepts), structural knowledge (interrelationship of concepts in memory), and procedural knowledge (how to apply the structure knowledge). Also, as learners identified the IF-THEN structure of a domain, they tended to have a deeper understanding of the task nature and make the subsequent practices more meaningful.

Lippert (1988) described the development of expert system rule bases to solve problems about forces by six freshmen physics students. Students used an expert system shell, a tool that can take knowledge base and make them functioning entities, to create questions, decisions, rules and explanations regarding classical projectile motion.

After instructions on various examples of force phenomena, students could begin to synthesize their knowledge of the force types by constructing a knowledge base. The teacher introduced the expert system to students and explained the format of IF-THEN rules. Students were then assigned to groups and given the task to construct the rule base. The researcher also noticed that engineering students who designed a knowledge base on rockblasting techniques and education students who built a knowledge based on instructional design even mastered the content that they were originally not expected to master. The knowledge bases they built showed that they purposefully had reviewed a great amount of information. The researcher concluded that the use of expert system provided a learning environment where students can improve their higher-level thinking skills, problem solving and acquisition of domain specific knowledge. He further pointed out that expert system had the potential to merge three roles, tutor, tutee, and tool, into a single system.

The research on expert system as cognitive tools is very limited. More research needs to be done to investigate how the construction of an expert system knowledge base supports cognitive process and learning.

Computer Programming Languages as Cognitive Tools

The only language that a computer can recognize is a series of bits and bytes that provide computer with instructions on how to carry out certain operations. This is called machine language. Programming languages are abbreviated forms of instructions that certain programs can translate into machine language so that the computers can understand. Programming using programming languages is a very complex process. Taylor (1980) stated that learning to program is an activity that develops higher-order thinking skills. Thus, programming languages have often been taught in schools hoping to help develop students' thinking and reasoning skills.

Most educational research on the use of computer programming languages focused on how much the logical reasoning required to program can be generalized or transferred to other problem situations (Jonassen & Reeves, 1996). The research findings are inconsistent. Lisao and Bright (1991) conducted a meta-analysis of research on the effects of computer programming on cognitive outcomes. The results showed that the majority of studies found that students who learned to program scored higher on various cognitive tests than those who did not. However, the difference was not large.

An exemplary study on the use of programming languages as cognitive tools was done by Harel (1991) in her Instructional Software Design Project (ISDP). Seventeen fourth-grade students participated in the study. They used LOGO for one semester to create software products that can teach fractions to third-grade students. Students are also required to write in "Designer's Notebook" every day and attend periodic "Focus Sessions" on software design, LOGO programming, and fractions. Collaboration was also encouraged among students. Harel compared the differences in LOGO skills and fractions knowledge between the 17 students and 34 other students who were studying the same material via traditional teaching method. A combination of quantitative, qualitative, and comparative research methods were used. No significant differences were found through quantitative methods. However, Harel reported that the general trend was rather positive in terms of specific learning outcomes as shown in tests, exercises, observations and interviews. According to her observation, "…students were constantly involved in metacognitive acts: learning by explaining, creating, and discussing knowledge representation, finding design strategies, and reflecting on all of the above" (p. 359). Harel successfully integrating learning programming into a problem solving environment and took a "learners as designers" approach.

Studies on learning to program as a cognitive tool are generating disappointing and inconsistent results. According to Jonassen & Reeves (1996), the reason lies in the complex nature of programming languages and the difficulty to learn to program. The cognitive overhead needed in programming is too high that it interferes with learners' ability to use it as a tool to solve problems. As we discuss the rest of the cognitive tools, we can see that all of them are reasonably easy to learn and handle. Programming language is for sure a powerful cognitive tool for proficient programmers. However, the usefulness of programming languages as cognitive tools to non-programmers is questionable.

Spreadsheets as Cognitive Tools

A Spreadsheet is a matrix or table of empty cells with columns identified by letters and rows identified by numbers. Each cell is placeholder for values, formulas, or functions. Spreadsheets are generally used as computerized, numerical record keeping systems.

Spreadsheets may be used as cognitive tools for amplifying mental functioning (Jonassen, et al. 1998). For instance, building a spreadsheet requires learners to have abstract reasoning and become rule-makers, because spreadsheets are rule-using tools. All the calculations are based on pre-specified formula or functions. Using the spreadsheet may also improve learners understanding of underlying interrelationships and procedures. However, there has been very little empirical study on the use of spreadsheets as cognitive tools. Most studies on spreadsheets did not investigate the cognitive requirement and effects of spreadsheets. There is one rare study conducted by Sutherland and Rojano (1993) investigated spreadsheets as cognitive tools. The study was conducted in Britain and Mexico at the same time and lasted 5 months. During this period, students used spreadsheets to represent and solve algebra problems. They moved from cause-effect local numerical notion of algebraic relationships to rule-governed relationships that were symbolized in spreadsheet. However, the study didn't provide any empirical evidence of the effect of spreadsheets as cognitive tools.

Several recent articles described the use of Spreadsheets as learning and cognitive tools. However, none of them provided empirical evidence to validate their assumptions. Abramovich, Stanton, and Baer (2002) demonstrated how multiple features of a Spreadsheet tool extended motivational activities and enhanced mathematical thinking of younger children in the context of data analysis and probability. The project took place in a small rural school in upstate New York. Students aged 8-9 years old. A computer program that used spreadsheet-enabled M&M (candies) mathematics was used. Based on their observation, Abramovich et al. suggested that Spreadsheet free students from the tedious paper-and-pencil graphing and enable them to concentrate more on mathematical tasks. In addition, Spreadsheets allowed students to surpass physical and developmental limitations associated with their age. As a result, high level of success in students' performance on the assignment was observed. Furthermore, Dugdale (2001) looked into the effectiveness of Spreadsheets on exploring mathematical patterns and building conceptual understanding of variables and functional relations. He found that students' explorations of math relationships combined five representations of the problem: the spreadsheet formulas, the spreadsheet table, a line graph connecting consecutive entries, a scatter plot of points, and a connected scatter plot. Thus, he reported that students used the Spreadsheet environment for dynamic exploration and visualization of mathematical relationships. Villiers (2003) and McMillan (2003) also reported the use of Spreadsheet as cognitive tools. Again, neither of them provided valid empirical evidence.

Although the use of spreadsheets as cognitive tools sounds promising, research on the cognitive outcomes from using spreadsheet is needed to prove the assumptions.

The use of spreadsheets as cognitive tools will remain speculative until there are significant findings from formal empirical research.

Computer Microworld Environments as Cognitive Tools

A computer microworld is "an environment that allows the learner to explore and manipulate a rule-governed universe, subject to specific assumptions and constraints, that serves as an analogical representation of some aspects of the natural world" (Pea, 1984). It is an exploratory learning environment, where learners can navigate, manipulate, and interact with. It is capable of providing learners with a set of cognitive tools to support their learning.

Lajoie (1993) investigated the use of cognitive tools in two computer microworld environments: Sherlock I and Bio-World. Sherlock I is a simulation of an avionics shop for students to learn troubleshooting skills. Bio-world is a simulation of a hospital environment where students learn to diagnose infections. Both microworlds integrated the four types of cognitive tools that support learners' cognitive processes, share the cognitive load, allow learners to engaged in "out-of-reach" cognitive activities, and allow learners to generate and test hypotheses. Studies on these two microworlds yielded positive results.

Lesgold, Lajoie, et al. (1988) studied the use of Sherlock I at two Air Force F-15 bases. The experimental group worked through Sherlock's 34 problems. And tutoring sessions were conducted 2-3 hours per day for an average of 12 working days. The control group went through the daily activities in an avionics shop. Pretest and posttest of troubleshooting were administered in a form of structured interview. The problems in pretests and posttest were based on actual problems with authentic Air Force technical orders. The results showed that the experimental group solved more problems than the control group. In order to further investigate whether the two groups differed in the quality of their problem-solving solutions, a scoring template was developed to examine qualitative differences in troubleshooting performance on pretest and posttest data. Using the scoring system, Lajoie & Lesgold (1992) did a qualitative analysis of the pretest and posttest data. The analysis showed that the experimental group was significantly different from the control group in that the experimental group had a higher proportion of expert-like steps to solve the problem in the posttest ($F(1, 27) = 28.85$, $p<.01$), and it also had a lower proportion of inappropriate moves to solve the problem ($F(1,27) = 7.54$, $P<.01$). A repeated measures analysis of variance focused on the type of steps revealed that the percentage of expert steps increased in experimental groups over the course of tutoring ($F(2,45) = 7.20$, $P<.002$).

Lajoie (1993) pilot-studied the other microworld, Bio-world, on eighty-four 9th grade high school students. Students worked in groups of 3 consisting of one high, one medium, and one low ability level student. They spent 25 minutes working on a diagnosis problem. The analyses showed that students' confidence level increases as they collect more information from the program. There was a significant difference in confidence ratings between the first and the last diagnosis that students entered

(Friedman ANOVA, test statistic =7.0, $p = .01$). As a result, the research suggested the integration of affective assessment and cognitive skills assessment to study students' learning in Bio-world.

Therefore, Lajoie concluded that there was adequate proof to support the notion that "computer can be used as cognitive tools for learning, restructuring of knowledge, mental model building and promoting confidence in problem solving" (Lajoie, 1993, p. 285).

Hypermedia / Multimedia Authoring Systems as Cognitive Tools

Hypermedia/Multimedia is the sequential or simultaneous use of a variety of media formats in a given presentation or self-study program. Multimedia is now frequently used to build interactive environments that not only include various media but also support interactivity and leaner-control. Researchers believe that the use of multimedia can enhance students learning.

Researchers believe that hypermedia/multimedia can be used as cognitive tools, especially in cases where students constructing hypermedia/multimedia materials instead of studying those created by others (Jonassen & Reeves, 1996). Hypermedia construction is in line with constructivist view of learning process as collaborative knowledge construction process. Carver, et al. (1992) listed some of the major thinking skills learners are involved in while designing multimedia materials: project management skills, research skills, organization and representation skills, presentation skills, and reflection skills. However, the engagement of these skills in designing multimedia materials still needs to be empirically validated.

Lehrer (1993) conducted an exemplary study on the development, use, and result of Hyper-Author used by eighth-graders to design their own multimedia lessons on American Civil War. The study included both high and low ability eighth-grade graders. The students worked on the multimedia construction tasks for 45 minutes every day over several months. A computer, scanner, sound digitizer, HyperAuthor software, and print/non-print resources about the Civil War were available to students. An instructor was also coaching students in the design and production of the multimedia program. At the end of the study, a teacher-constructed test was administered to the hypermedia group and the control group who studied Civil War through traditional classroom method. No significant differences were found. However, students were interviewed a year later by an independent interviewer. Students in the control group could recall almost nothing about any of the historical content, while students in the design group were able to elaborate concepts and ideas that they had extended to other areas of history. Moreover, students in the design class also viewed history as a process of interpreting the past from different perspectives instead of a series of facts. The hypermedia design approach led to richer, connected, and more applicable knowledge. Lehrer also pointed out that "the most striking finding was the degree of students' involvement and engagement" (p. 209). Both high and low ability students were very task-oriented and gained increasingly more confidence with the hypermedia authoring tool. Another study conducted by Lehrer, et al. (1994) on ninth-graders' use of HyperAuthor to develop hypermedia about World War I also yielded similar results.

Over the past few years, Liu and her colleagues have conducted a series of studies on the effect of multimedia authoring on learning in a learner-as-multimedia-designer environment (Liu, 1998a; Liu, 1998b; Liu & Pedersen, 1998; Liu & Rutledge, 1997, Liu & Hsiao, 2001; Liu & Hsiao, 2002). In addition to the learn-by-design approach, the multimedia authoring process carried out in these studies also tried to simulate the multimedia industry practice as close as possible. Students are generally involved in three phases during the entire multimedia design project. In phase I, students learn multimedia tools such as HyperStudio and Macromedia Director and get used to the learning environment. In phase II, they switch focus to multimedia design and production following a 4-stage process adapted by the multimedia industry: planning, design, production, evaluation and revision. Finally, in phase III, the process in phase II is repeated with a new focus such as working on a real-life multimedia project. Students are provided with additional opportunities to practice and internalize knowledge.

To evaluate the effects of the learner-as-multimedia-designer environment, a range of quantitative and qualitative measures were used in these studies such as project design questionnaire, resource management strategy questionnaire, design task ranking, performance assessment, concept maps, interviews, observations, and response logs. The findings can be organized into three levels.

At the high school level, Liu (1998b) found that students' motivation scores in intrinsic motivation, task value, learning belief, and self-efficacy were significantly increase from pretreatment to post-treatment (multimedia design project as treatment condition). Moreover, students' understanding for planning, searching information, connecting ideas, importance of audience, and collaboration was also significantly increased. In addition, this study included an extended treatment (one-year-long instead of one-semester-long). The researcher pointed out that the second semester of working with and designing for a real client led to bigger changes in students' motivation and design knowledge. For example, significant changes found in searching information, connecting ideas, and importance of audience were not found in the previous study (Liu & Rutledge, 1997). Finally, the results showed that cognitive apprenticeship principles such as modeling, coaching, scaffolding, fading, articulation, reflection, and exploration, are helpful in designing learner-as-multimedia-designer environment.

At the middle school level, Liu & Hsiao (2002) found that learner-as-multimedia-designer environment facilitated the development of cognitive skills of middle school students, and engaged them in active learning. This study took place in the Spring semester of 2002. Sixteen 7^{th} graders participated in a multimedia design class. The study followed the three-phase procedure that we discussed earlier. The statistics analysis showed that students' design knowledge increased significantly from pre- to post- semester ($p<.01$ in concept mapping). More importantly, the task ranking data showed that students became aware of the various steps involved in multimedia authoring, and realized the significant of planning, designing, and testing stage. However, the T-test on strategy use questionnaire showed that students' time and study environment management decreased significantly, although their peer learning strategy use significantly increased. The researcher pointed out that middle-school students might not be cognitively ready to manage time and effort well in multimedia authoring environment.

At the elementary school level, Liu (1998a) found that through participating in multimedia authoring, 4th graders' creative thinking scores increased significantly in the measures of fluency, elaboration, and resistance to premature disclosure. However, no differences were found in the measures of originality and abstractness of titles. The overall posttest creativity score was moderately significant ($p < .07$). It was also found that multimedia authoring benefited students of all ability levels. However, the intermediate-ability students gained more than the low-ability and high-ability students. In addition, collaborative group benefited more than the individual group. Finally, the results of the achievement tests showed that students' knowledge on the subject matter was significantly increased from the pretest to the posttest ($p<.01$; $p<.01$). Thus, the researcher concluded that multimedia authoring can promote students' motivation and facilitate their cognitive development.

Lehrer and Liu's studies considerably contribute to our understanding of multimedia authoring environment as cognitive tools. Their findings provide important empirical evidence that multimedia/hypermedia authoring environments actively engage learners, facilitate collaborative knowledge construction, and support acquisition of higher level cognitive skills.

Besides hypermedia construction, there is a wide range of use of cognitive tools in hypermedia/multimedia environment. Cognitive tools can be designed to assist users in "locating key information, recording or modifying available resources, connecting available resources, generating and linking personally relevant ideas with existing multimedia resources, and creating individual pathways that link the various multimedia resources contained in the system" (Liyoshi & Hannafin, 2002). Even though the use of multimedia/hypermedia is approved to be effective as cognitive tools by a number of studies, there is a need to investigate the effects of hypermedia/multimedia on the development of higher-order thinking skills such as framing and resolving ill-defined problems. Alternative assessments on those cognitive outcomes need to be implemented. The design and development of reliable, valid, and feasible cognitive assessment is one of the most important tasks in studies on hypermedia/multimedia as cognitive tools.

Collaborative Knowledge Construction Environment as Cognitive tools

Collaborative knowledge construction environments enable students to explore the information, elaborate and explain their interpretation of the knowledge, compare their knowledge with that of the others', and evaluate and reconstruct their own knowledge. (Jonassen & Reeves, 1996).

Knowledge Forum (http://www.learn.motion.com/products/kf/index.html), the Web version of Computer Supported Intentional Learning Environment (CSILE), is a collaborative database that supports a structured knowledge construction environment through the use of a Web-based bulletin board system. In the Knowledge Forum, students pose questions, define their own learning goals, acquire and build a knowledge base, and collaborate with one another. Students use the bulletin board to create a database, in which they construct shared knowledge about particular content domains. The teacher's role is to monitor the forum and lead students through the knowledge construction process. The Knowledge Forum is a successful online collaborative tool that facilitates deep and effortful cognitive processing through the use of a set of cognitive tools. For example, the navigation and note keeping tools support learners' cognitive processes and share their cognitive load. Learners don't have to memorize the information. Instead, the note keeping tools allow learners to keep all the necessary information within accessible sections. Moreover, the navigation tools in the Forum enable learners to sort or search through all the related resources and notes on certain topics. Thus, learners are freed to perform higher order cognitive skills such as critical thinking. The most innovative feature of the Knowledge Forum is how the note building tools support collaborative learning. There are several tools learners can use to cooperate with each other. The co-authoring tool allows a number of learners to co-edit the same note. Learners are even given the option to choose the specific persons they want to work with. The build-on tool allows learners to respond to the existing note by adding a new note showing their thoughts, ideas, or responses. The reference tool allows learners to refer and link to resources on related knowledge. All these tools work together to build a collaborative knowledge construction environment in which learners can cooperate to build networks of ideas; construct, store, and retrieve information; and construct their own knowledge.

Greer, Mccalla, Cooke, Collins, Kumar, Bishop, and Vassileva (2000) showed the implementation of another kind of collaborative knowledge construction environment. They developed a set of cognitive tools to support peer help, which is an important aspect of collaborative learning that usually occurs within collaborative groups naturally. Peer Help not only provides cost effective assistance to students, but also promotes self-explanation and reflection in the helper. Greer et al. integrated cognitive tools into two systems: the Collaborative Peer Response System (CPR) and Peer Help System (PhelpS). CPR provides a discussion forum where students can post questions and provide answers; an accounting system to keep track of students' use of peer help; a FAQ; tools to help a moderator construct and organize FAQ; and a database of potential peer helpers. PhelpS incorporates artificial intelligence techniques and provides ways to locate a particular peer helper who is likely to know the answer based on certain help request. CPR, together with PhelpS, integrates several cognitive tools into an intelligent intranet peer help desk facility – a collaborative knowledge construction environment in which students are able to explore the information, elaborate and explain their interpretations of knowledge, compare their knowledge with that of others, evaluate their own knowledge, and so on. The Help Desk system itself can be viewed as a cognitive tool which " creates cognitively determined conditions for peer help and collaboration to happen by selecting the appropriate help resource, which is based on modeling student knowledge and on a cognitive model of the subject material"(Greer et al., 1999).

Recently, Schank and Kozma (2002) investigated the use of a Knowledge Building Environment in both high school and college chemistry course. ChemSense, the Knowledge Building Environment is a virtual workspace for students to express and discuss ideas in chemistry. It provides a range of tools to support student generation of chemistry representation, discussion, and knowledge building. Specifically, ChemSense supports the sharing, viewing, and editing of various chemistry representations, including text, image, graphs, molecule drawings, and even animations. The researchers reported the findings from a couple of classroom studies on the use of ChemSense. The results showed that students who used ChemSense showed significant improvement in representational competence and their understanding of connectivity and geometry from pre- to posttest ($p<.05$). Most importantly, students with low representational competence benefited the most from this collaborative knowledge construction environment ($p<.05$). In addition, qualitative data analysis revealed that the use of the tools in ChemSense required students to think harder and more carefully. Thus, the researchers concluded that ChemSense, as a knowledge construction environment, allows students to collaborate in the investigation of chemical phenomena, collect data, build representation of those phenomena, and participate in scaffolded discourse to explain the underlying principles. The knowledge construction environment facilitates students' chemical understanding and representational ability.

The above studies provided valid empirical evidence that Knowledge Construction Environment can incorporate various cognitive tools to support learners' collaborative knowledge building process and facilitate learning. The integration of such environment is especially critical in distance learning context, where students have no real contact with each other or the instructor.

Combined Cognitive Tool Use in Classrooms

Cognitive tools have been increasingly used in classrooms. However, most research studies on cognitive tools investigated the effect of one specific type of cognitive tools or a combination of cognitive tools in a particular hypermedia/multimedia software learning environment. Very limited research is focusing on the effect of combined cognitive tools use in regular classrooms.

Reeves et al. (1997) described the development, implementation, and effects of the use of computer-based cognitive tools in an undergraduate engineering course (ENGR110) at the U. S. Air Force Academy. Several cognitive tools including the WWW, spreadsheet, PowerPoint, e-mail are employed in the course. They provide students many opportunities to use these tools within the course. For example, to complete several "hands-on" projects such as building and flying model rockets, students need to collect data and entered them into spreadsheets for calculation. A website was also constructed to support students' access to the wealth of information on course subject. In addition, at the end of the course, PowerPoint was used for team briefing. Research data was collected through the Reflective Judgment Exercise (RJE), students self-report (focus group, questionnaires, and email surveys), and interviews. Results showed statistically significant differences in "problem solving" between the group of students who used the cognitive tools and the two control classes. The use of cognitive tools helps increase students' ability to frame and resolve ill-defined problems.

Reeves et al. suggested that higher order learning outcomes can be achieved through the implementation of cognitive tools. Future efforts to use media and technology must be guided by more research on computer-based cognitive tools.

Pedagogical Agents: A New Cognitive Tool?

Over the past few years, a number of studies have shed light on a new pedagogical tool in education – pedagogical agent. Pedagogical agents are animated characters designed to operate in an educational setting for supporting or facilitating learning (Shaw, et al., 1999). To date, pedagogical agents are mainly used in open learning environments where learners explore the environment with the support of various cognitive tools. The rationale for the design of pedagogical agents lies in the fact that sometimes, students in open learning environments are not capable of using the support tools appropriately and eventually get lost in the learning environment (Clarebout, Elen, Lowyck, Vanden Ende, & Lagano, 2000, Lank, 2000, Hill and Hannafin, 2001). Pedagogical agent, therefore, provides resources and manages mediating intervention through six types of roles: supplanting, scaffolding, demonstrating, modeling, coaching, and testing. Some pedagogical agents that are currently in use include Adele, Steve, Herman the Bug, Cosmo, WhizLow, Jacob, and so forth.

Although pedagogical agents are only recently being introduced to the field of education, some research has already been done on the effects of pedagogical agents on learning. Moreno, Mayer, and Lester (2000) investigated the use of a pedagogical agent (Herman the Bug) in a discovery learning environment. Students were randomly assigned to two treatment groups. One group had a pedagogical agent, while the other only received text-based information. Measures on retention, transfer, and self-rating were administered. No significant difference was found for the retention test. However, the Pedagogical agent group significantly outperformed the other group on the transfer test. Students who used pedagogical agents also showed a greater interest and motivation. In a follow up study, Moreno, Mayer, and Lester (2001) experimented with pedagogical agents varying on the three modality effects: image, voice, and onscreen text. The results showed that interactive pedagogical agents who communicate with students via speech resulted in better retention and transfer. However, the mere presence of an image of the pedagogical agent had no cognitive or motivational effect.

In addition, students who learn in an environment that involves participation between agent and learners are more actively involved in processing lesson materials.

While current research support the use of pedagogical agents to facilitate learning in open learning environments, the influence of these agents on cognitive processing and learning remains unclear. The potential of pedagogical agents as cognitive tools still needs to be further investigated.

This literature review has investigated a large body of research on cognitive learning theories, cognitive skills and their acquisition, and computer-based cognitive tools. It provides a profound research base that contributes to the design and implementation of the study described in the next chapter.

Chapter 3: Design

One major concern was raised in the review of literature. Despite the perceived benefits of a wide range of computer-based cognitive tools, there is a lack of empirical evidence to support the effects of databases as cognitive tools. This study seeks to determine if a database tool can share learners' cognitive load, facilitate their cognitive skills acquisition, and improve learners' overall performances. In the first part of this chapter, I will briefly discuss Alien Rescue – the learning environment for this study, and the rationale for the design and development of a database tool. In the second part of this chapter, I will lay out the design of this study.

A PBL MULTIMEIDA / HYPERMEDIA ENVIRONMENT

In this study, <u>Alien Rescue</u>, a computer-based PBL hypermedia learning environment, was used as the science curriculum for a 4-week period. <u>Alien Rescue</u> is designed for sixth grade science classes. It begins with a presentation of an ill-structured problem for students to solve. The problem is as follows: a group of six alien species have arrived in the Earth's orbit due to the explosion of their home planets. They plan to find new homes that can support their life forms. However, their spaceship was damaged during the voyage. Therefore, they send messages to Earth to ask for help. Students, then, take the role as young scientists participating in the worldwide effort to rescue the alien species. Their job is to research suitable planets for the six alien species. Throughout the program, students have to engage in a variety of problem-solving activities. They research about what the aliens need, what the planets in our solar system can offer, and find possible matches.

In addition, Alien Rescue presents a very complex and ill-structured problem that is not easy for an individual to solve. For such a demanding cognitive load and workload, distribution of labor is need for problem solving. Collaboration is an integral component of Alien Rescue. Pedersen (2000) reported that many students divided the labor with their group members and found out that this collaboration helped them work more quickly and efficiently. In addition, this collaboration among students also allowed students challenge each other's ideas, which resulted in better solution of the problem.

To support students' learning and problem-solving processes, the Alien Rescue environment provides learners with a set of cognitive tools. These tools are available through a two-layered interface in Alien Rescue. The first layer is the virtual international space station (see figure 3.1), which consists of five active rooms, each containing an instrument that students can use to gather information. These five rooms are the Conference Room, the Research Room, the Probe Design Room, the Probe Launch Room, and the Control room. The second layer is the imaginary goggles students wear wherever they go in the space station. It appears as an overlay of the five rooms, which consists of a series of tools linking the sides and bottom of the screen.

This second layer contains a range of tools such as Notebook, Solar System Database, Mission Database, Concept Database, Charts, Message, and Experts (see figure 3.1).

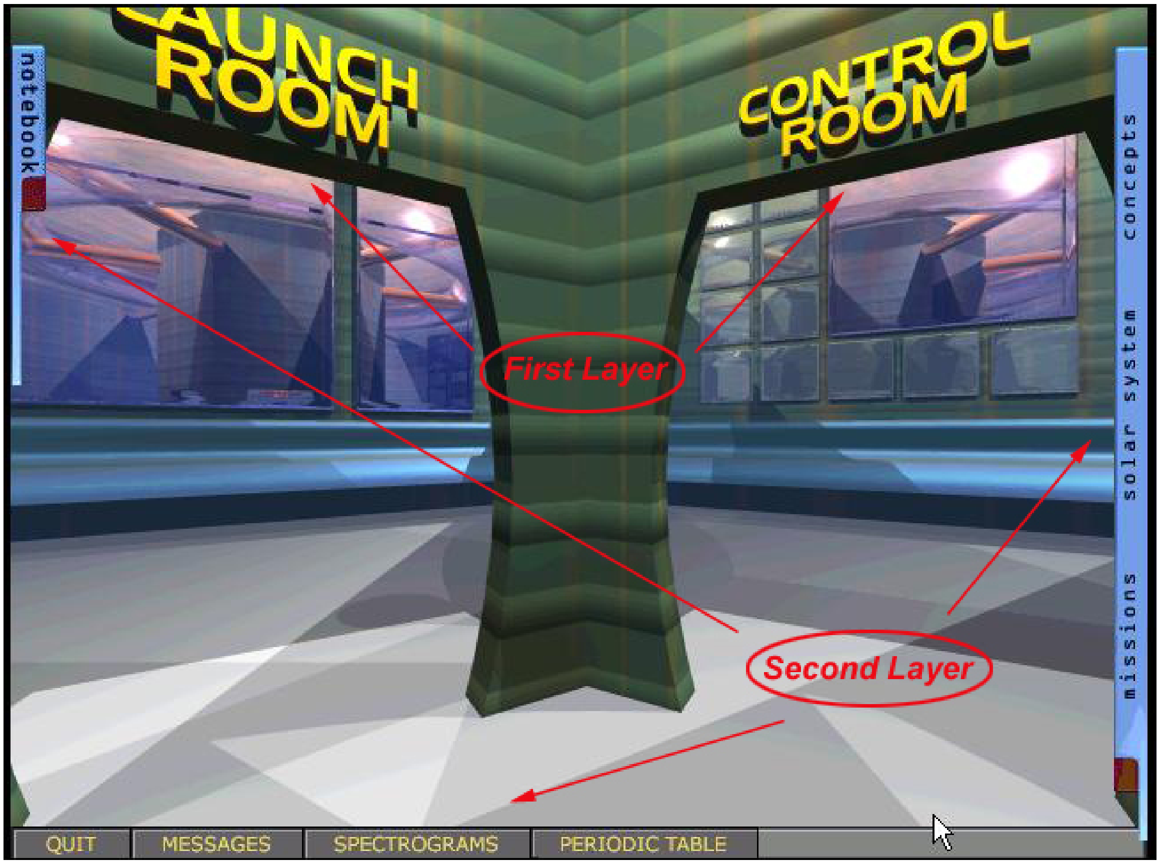


Figure 3.1 Examples of First and Second Layers of Cognitive Tools in Alien Rescue

Based on Lajoie's (1993) definition, the cognitive tools in Alien Rescue can be grouped into four categories: 1) tools that share cognitive load, 2) tools that support cognitive process, 3) tools that support cognitive activities that would otherwise be out of reach, and 4) tools that allow hypothesis generation and testing. The four knowledge databases mentioned above are examples of tools that share cognitive load. They store a huge amount of multimedia-enriched information into organized patterns and reduce the memory burden for students. The expert tool is an example of the second type of tools that support cognitive processes. It consists of videos of expert scientists explaining how they would deal with specific aspects of the problem, sharing stories about their experiences. It supports and extends learners' thinking processes through expert modeling. Examples of the tools supporting cognitive activities that would be otherwise out of reach are the Probe Builder and Launch Rooms. Students can build and launch probes in a virtual place. Finally, examples of the tools that allow hypothesis testing are the Control Room and the Solution Form. Students can inspect the data coming back from probes in the Control Room to test their hypothesis and write up their solution using the solution form tool. Tools in categories 1 and 2 help students search the existing knowledge database, locate relevant information, and make effective decisions. While tools in categories 3 and 4 help students collect new data, interpret and organize data, establish rationale for their decisions, and present their solution reports. A list of the cognitive tools in Alien Rescue and their corresponding categories is included in table 3.1.

Table 3.1 Categorization of Cognitive tools in Alien Rescue

Categories	Cognitive Tools in Alien Rescue
Category 1	Alien Computer Database; Solar System Database; Mission Database; Concept Database; Notebook
Category 2	Expert Tool;
Category 3	Probe Builder; Launch Rooms
Category 4	Control Room; Solution Forms

Liu and Bera (2005) examined the use of the above cognitive tools by sixth graders. The analysis of the tool use patterns showed that students make productive use of the cognitive tools and are able to select appropriate tools based on the phase of the problem-solving process they are at. The uses of the Alien Rescue program in middle schools proved to be successful and support students' problem solving processing (Liu, et al., 2002; Liu & Bera, 2005; Pedersen, 2000; Williams, 1999). However, some issues also arose from the field-testing, which were discussed next.

Problems with the Notebook Tool

As a typical multimedia learning environment, Alien Rescue contains a large amount of information and requires complex problem solving. Learners have to search through hundreds of screens of information within the four knowledge databases. Very often, the cognitive load imposed on learners is fairly high. In order to solve this problem, a notebook tool was originally built into the Alien Rescue program to help reduce learners' extraneous cognitive load by providing a space for learners to store their research data so that they do not have to memorize the information or try to hold it in their working memory. However, there are three problems associated with the notebook tool.

The first problem is the organization feature of the notebook. The current notebook tool allows students to create multiple sections. Each section provides students with a blank space to type information. A pilot study conducted in 2000 on the notebook tool showed that most 6th grade students entered information in an unorganized fashion. They rarely used bullet points or numbers to organize their notes. Since the tool offered them a blank space to type, they tended to write long paragraphs with scattered information in them. This created chaos when the time came for students to make hypotheses or research plans utilizing the information in their notebook tools. Students wasted a significant amount of time reading through their notes and trying to make sense out of them. Even though an expert model tool was available to show students how to take notes, I found that students rarely referred to the expert model tool for note-taking purposes. The second problem is the one-dimensional feature of the notebook tool. Students can create multiple sections; however, they cannot compare the sections. For example, if a student wants to compare notes on an alien with notes on one of the planets, he must first read the alien notes section, maintain the information in his working memory, and then compare information with the planet notes section. Thus, a huge amount of extraneous cognitive load is posed on students. And finally, the notebook tool does not contribute to germane cognitive load. Even though it helps to reduce the amount of information students have to hold in their working memory while exploring the Alien Rescue environment, it does not have any features that support learners' schema constructions. Based on cognitive load theory, learning is optimized if there is a simultaneous reduction of extraneous cognitive load and an increase in germane cognitive load. Thus, as a cognitive tool, the notebook tool in Alien Rescue does not provide sufficient support to share learners' cognitive load.

Cognitive Skill Requirements

One of the major goals of Alien Rescue is to support problem-solving process. In order to solve problems, learners have to locate relevant information, make comparisons, construct hypotheses, and make decisions. In addition, there is an enormous amount of information in Alien Rescue, which requires learners to constantly perform the task of eliminating irrelevant and redundant information. Thus, identifying key information, organizing related information, evaluating information, and making comparisons are crucial to success in Alien Rescue. To successfully perform these cognitive tasks, learners have to possess certain cognitive skills such as categorizing, organizing, comparing, and evaluating. Yet, not all 6th graders have those skills and are cognitively ready to perform them. Some students have a hard time organizing, sorting, and identifying the important information, not to mention comparing, evaluating, and synthesizing information.

During the pilot uses of Alien Rescue, teachers designed some simple charts to help students categorize and organize information. However, this paper-based chart did not meet all students' needs. For example, in order to compare notes on different aliens and worlds, students had to dig through more than ten charts to find the required information. Moreover, students could not always remember the information categories they created. They constantly ended up creating different categories for different aliens and worlds, which made the information comparison even harder. In addition, keeping track of charts on twenty pieces of paper was not an efficient way to record and handle data.

Given the pilot testing results and the limitations of the current notebook tool, the researcher suggested a new cognitive tool to be built into the Alien Rescue environment to replace the notebook tool and the paper charts. This tool should provide better organizational support, share learners' cognitive load, promote germane cognitive load, and facilitate the acquisition of appropriate cognitive skills.

Design and Development of an Online Database Tool

Database management systems allow users to store, manage, search, and sort information in the databases. As applied to educational context, students can use the databases to analyze and enter relative information, which can then be searched and sorted to answer specific questions or to identify interrelationships among the information. In addition, several researchers reported that the use of database applications involved higher level thinking skills such as analyzing, synthesizing, and evaluating information (Pon, 1984; Rooz, 1988; Watson & Strudler, 1988). Thus, the researcher proposed that the new cognitive tool that we called for in the last section could be a customized database tool.

This online database tool was designed and developed in Spring 2003. It has four key features. 1) It allows students and instructors to have individual accounts. In order to use the database, users need to log into the database using their assigned login names and passwords (see Figure 3.2). Therefore, students can only access information in their own accounts. However, an instructor can access all the information her students have entered. 2) It contains a series of tables with rows and columns for students to enter data. Each table is pre-assigned to hold information for one of the alien species or one of the planets in the solar system. All alien tables are grouped together and all planet tables are grouped together. Students can choose from drop-down menus to go to any one of the tables to enter information they have collected (see Figure 3.3). They can also go back to edit the information they entered previously. 3) Students can create various information categories/fields in the tables (see Figure 3.4). Once a category is created, it becomes universal to all tables. For example, if a student creates a category named "atmosphere" in the Mercury table, all tables automatically have an atmosphere field added. However, this only affects tables within that student's account. 4) There is a build-in query function in the database tool (see Figure 3.5). This query function enables students to make multiple comparisons between information in an alien table and information in a planet table. Students simply choose the specific alien and planet they would like to compare with and click the "compare" button. A report is then generated with alien and planet information side-by-side under each category (see Figure 3.6).

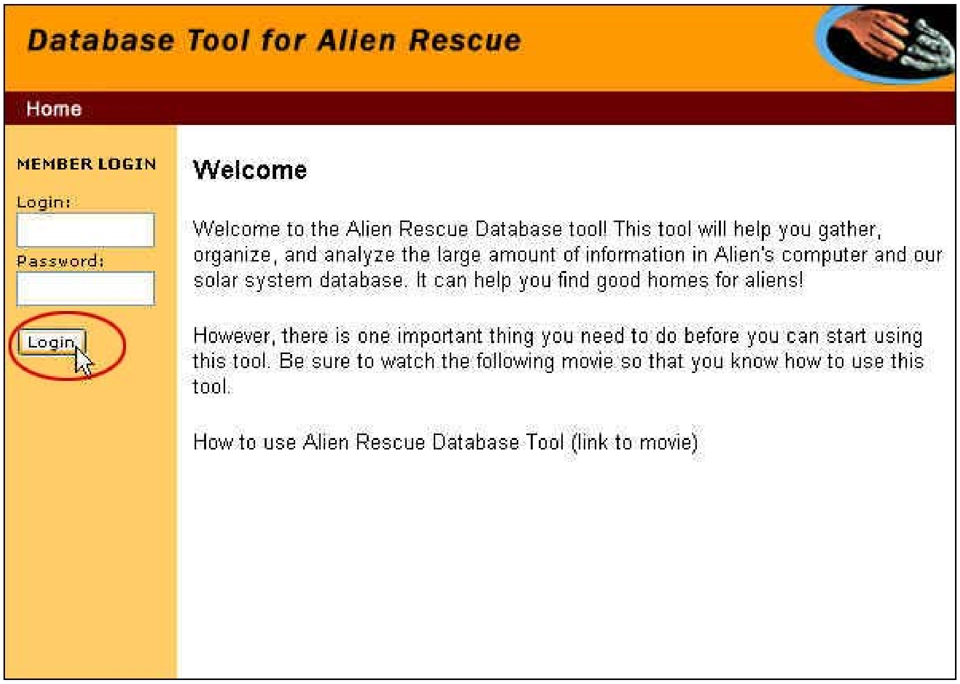


Figure 3.2 **Login** Screen for the Online Database Tool

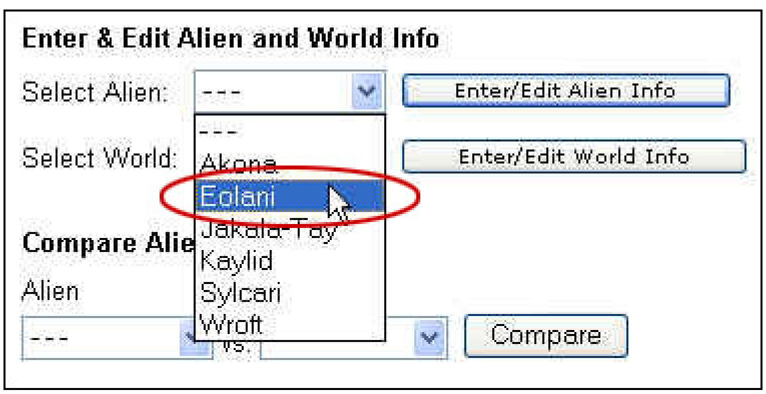


Figure 3.3 Drop-Down Menu to Access Planet Tables

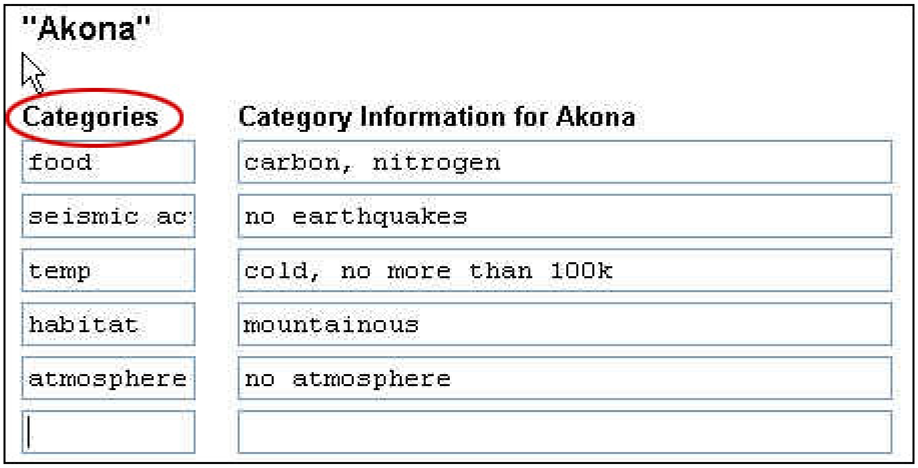
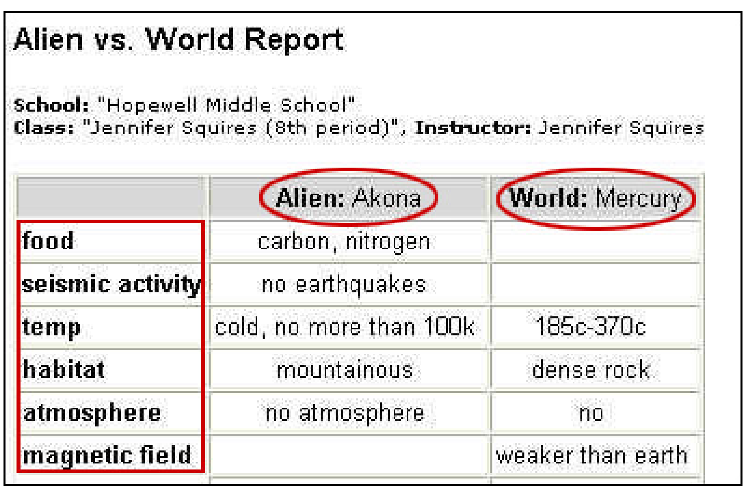


Figure 3.4 Create Categories in Tables

Figure 3.5 Perform *Compare* Function in the Database


Alien vs. World Report

School: "Hopewell Middle School"
Class: "Jennifer Squires (8th period)", **Instructor:** Jennifer Squires

	Alien: Akona	**World:** Mercury
food	carbon, nitrogen	
seismic activity	no earthquakes	
temp	cold, no more than 100k	185c-370c
habitat	mountainous	dense rock
atmosphere	no atmosphere	no
magnetic field		weaker than earth

Figure 3.6 Alien vs. World Report

In order to use the online database tool, students have to be involved in various cognitive tasks. Firstly, students have to search the entire Alien Rescue knowledge database to locate the relevant information to be placed into various database tables. In addition, they must also discriminate between irrelevant and relevant information. Secondly, prior to entering information into the database, students have to create categories based on the information they have gathered, and further organize the information under each category. Thirdly, after a certain amount of information has been gathered and entered into the database, students should start performing queries to compare information from one table to another. Through the query function, students can form hypotheses, make connections and comparisons among various pieces of information, analyze and evaluate the query results, and develop plans for future data collection and problem solving. The process of the use of the online database tool can be illustrated as follows (Figure 3.6).

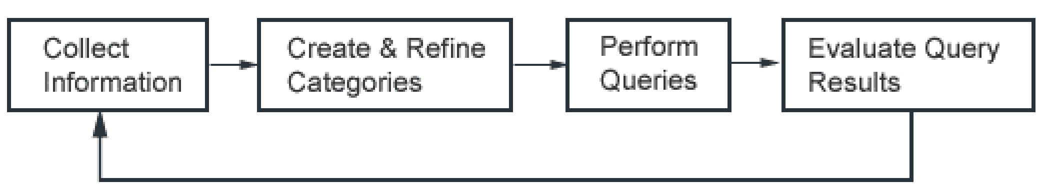


Figure 3.6 The process of the use of the online database tool

The cycle of collecting information, creating and refining categories, performing queries, and evaluating information provides opportunities for students to process information more deeply, and solve problems more efficiently.

Thus, through the use of this online database tool, students should obtain better cognitive skills on organizing, categorizing, analyzing, and evaluating information. They should also be able to solve problems in a more efficient manner. A list of the database activities and their related cognitive skills are listed in Table 3.2.

Table 3.2 Database Activities and Their Related Cognitive Skills

Database Activities	**Cognitive Skills**
Collect & Input Information	• Differentiate relevant information from irrelevant information. • State and rephrase information
Create & Refine Categories	• Categorize information • Organize information under categories
Perform Queries	• Form hypothesis • Compare information
Evaluate Query Results	• Analyze and evaluate query results • Locate missing/inconsistent information • Revise research plans

Furthermore, the use of this online database tool should also facilitate learners' schema construction. Information is constantly sorted, organized, and deeply processed to be saved in the long-term memory. Therefore, germane cognitive load should be increased through the use of the database. At the same time, extraneous cognitive load should be reduced since the database tool functions as a storage place to help students hold a huge amount of information.

To test the usability of this online database tool, it was piloted in a sixth grade classroom in Spring 2003. The pilot study showed that the use of the database tool helped students organize information, compare and analyze information, and evaluate information for future data collection and research. The analysis of students' scores on the cognitive skill transfer measure showed that the difference between the treatment group and the control group approached the level of significance ($p = .068$). However, no statistically significant difference was found on achievement tests.

This pilot study was limited in scope. For example, it did not investigate the effects of databases on learners' cognitive load. No measure on cognitive load was used. In addition, since this was a pilot program, the methods for best practices had not yet been established. Therefore, the instructor and the researcher spent a lot of time identifying management issues for the database tool. The full potential of the tool still remained to be explored.

RESEARCH QUESTIONS

This study continued investigating whether databases can function as cognitive tools to facilitate cognitive skills acquisition and to share cognitive load. A paper-based database tool was also included to further investigate whether the computerized (online) database tool is more effective than the traditional paper-based database tool (information tables on paper). Some of the measures used in the pilot study were also included in this study (e.g. the factual knowledge test).

The study intended to address three major research questions:

1. Do the online and the paper-based database tools under investigation share learners' cognitive load by reducing extraneous cognitive load and increasing germane cognitive load? Does the online database tool share learners' cognitive load more effectively than the paper-based database tool?
2. Do the online and the paper-based database tools under investigation facilitate students' acquisition of cognitive skills such as organizing, categorizing, analyzing, and evaluating? Does the online database tool facilitate learners' cognitive skill acquisition more effectively than the paper-based database tool?
3. Do the online and the paper-based database tool under investigation affect learners' performance in a hypermedia PBL environment? Does the online database tool improve learners' performance more effectively than the paper-based database tool?

SAMPLE

The participants were students from 6 intact sixth grade science classes at a suburban middle school in the southern United States. Two science teachers taught the classes. Both teachers have been using Alien Rescue for 3 years and are very familiar with the program. Each teacher taught three classes. The three classes were chosen according to teacher's suggestions to match students' abilities as well as convenience considerations. Each class consisted of similar percentage of low-, intermediate-, and high-ability students and was randomly assigned to one of the three treatment conditions: online database, paper-based database, and non-database. However, due to administrative reasons, one of the online database groups consisted of all math excel students. Therefore, following the standard data analysis, an alternative data analysis was done to eliminate this variable. There were a total of 98 students participated in the study. 57.9% of the participants were Caucasian, 24% were Hispanic, 18% were African American, and 0.01% were Asian. In addition, 55 percent of the students were female, and 45 percent of the students were male.

TREATMENT CONDITIONS

Independent Variables

All participants completed the activities in Alien Rescue. One treatment variable was examined – the Database Tool. The tool offers information tables for students to enter, organize, and compare research data. It is designed to share students' cognitive load, support cognitive skill acquisition, and facilitate learning.

Three treatment conditions were used as the treatment variable: Online database condition, paper-based database condition, and non-database condition.

The Online Database Condition

In the online database condition, students were given access to an online database tool in addition to the Alien Rescue environment. Students used the online database tool for three weeks starting the second week of the Alien Rescue program.

During the first day of online database tool use, the researcher worked with the teacher to provide students general instructions on how to use the tool. Furthermore, a brainstorming session was also held to help students generate initial information categories. The teacher modeled identifying information categories and evaluating their relevance to the problem. In this way, students were stimulated to think about how they would use the database tool later in the Alien Rescue program.

Then, students used the online database tool daily when they used the Alien Rescue program. The teacher set up a 10-minute time period at the end of each class session for students to use the online database tool. Students used this time to enter information, create categories, and perform comparison queries.

The Paper-based Database Condition

In the paper-based database condition, students were given access to a paper-based database tool in addition to the Alien Rescue environment. This paper-based database tool was designed to mimic the functions of the online database tool. It consists of two major parts. The first part of the paper-based database has a series of information tables. Every alien and planet has its corresponding table. Student can collect and organize research data to put into each information table (see Appendix E). In addition, based on teachers' suggestion, most of the major information categories are pre-created in every table (e.g. temperature category) to help students take notes more efficiently. The second part of the paper-based database tool is an elimination chart, which was design to mimic the "compare" feature in the online database tool and to help learners compare aliens and planets to find possible matches and eliminate the wrong ones. It is a basic chart with Aliens' names as column labels and planets' names as row labels. Students can mark the intersection of a specific alien and planet in the chart as either "yes" or "no" to indicate whether it is a possible match or not (see Appendix E). Although this elimination chart is not nearly as efficient as the comparison feature in the online database tool, it does provide students with a tool to do basic comparison.

Students used the paper-based database tool for the entire duration of the Alien Rescue program. During the first day of paper-based database tool use, the researcher worked with the teacher to provide students general instructions on how to use the tool. Furthermore, a brainstorming session was also held to help students put information in relevant information categories. The teacher modeled identifying relevant information and put it under corresponding categories. Through this way, students were stimulated to think about how they could use the paper-based database tool later in the Alien Rescue program.

After the initial session, students used the paper-based database tool daily when they used the Alien Rescue program. Since the tool is paper-based and can be accessed at any time during the Alien Rescue use, no specific time period was set up for students to use the tool.

The purpose of this condition was to determine whether a paper-based version of the database tool would be equally effective as the online database tool. The inclusion of the paper-based database tool helped to isolate the effects of the computerization of the database tool from the effects of a simple traditional version of database.

The Non-Database Condition

In the non-database condition, students used the Alien Rescue program exclusively. They did not have access to either the online database tool or the paper-based database tool. Students simply took notes on paper. This non-database condition reflected a typical use of multimedia PBL environment (AR) without any database tools. Providing this condition made it possible to isolate the effects of the database tools from the effects of any other cognitive tools in Alien Rescue.

DATA SOURCES

To measure cognitive load, cognitive skills, and performance, both quantitative and qualitative data sources were used. The triangulation of the quantitative data and qualitative data provided a more complete picture of the effects of database tools on learning.

Quantitative Data

Task Difficulty Rating Scale

To answer the first research question, a subjective task difficulty rating scale was used to measure learners' cognitive load. This seven-point Likert scale is a modified version of Bralfisch, Borg, and Dornic's (1972) rating scale for measuring perceived task difficulty. For example, the question "Is the task difficult?" was modified to read "Is Alien Rescue easy to use?" Learners reported their invested mental effort on a one-dimensional seventh-grade symmetrical category scale by translating the perceived amount of mental effort into a numerical value. This scale was modified and used in several studies to measure learners' cognitive load (Paas, 1992, Paas & van Merrienboer, 1994). Gopher and Braune (1984) pointed out that subjects can introspect on their cognitive process with no difficulty in assigning numerical values to the imposed mental load or the invested mental effort. Paas (1992) found an internal consistency coefficient (Cronbach's α) of .90 using a comparable scale. Paas and Van Merrienboer (1994) also evaluated the scale as a highly reliable and sensitive instrument for the assessment of cognitive load (α =.82). Sweller et al. (1998) concluded that the subjective rating scale is valid, reliable, and sensitive to relatively small differences in cognitive load and thus is the most promising technique for research on cognitive load. This rating scale was provided to, explained to, and illustrated for students at the beginning of the experiment. It was administered to the students after their completion of the Alien Rescue Program. The complete rating scale is included in Appendix A.

However, a major limitation associated with the use of the task difficulty rating scale is that it is difficult to make clear predictions on different types of cognitive load (e.g, extraneous, germane cognitive load). Van Merrienboer et al. (2002) found that there are currently no measurement instruments available to make a distinction between extraneous cognitive load and germane cognitive load. The task difficulty rating scale can only report perceived mental effort that includes both aspects of cognitive load. To solve this problem, Paas and van Merrienboer (1993) invented a computational approach to investigate the relative efficiency of instructional conditions. It assumes that instructional efficiency increases when learners use less mental effort to achieve a given performance score, or demonstrate a superior performance than would be expected for a certain level of mental effort. An efficiency (E) score is calculated by transforming both mental effort (M) and performance scores (P) to standardized *z* scores, calculating the mean of these z scores for each experimental condition, and combining them into the following efficiency formula:

$$E = \frac{P - M}{\sqrt{2}}$$

Instructional efficiency is calculated according to these rules: if $P - M > 0$, then E is positive; if $P - M < 0$, then E is negative. The greater the value of E, the more efficient is the instructional condition. This method helps researchers make reliable predictions on whether the perceived cognitive load is the germane cognitive load that contributes to learning or the extraneous cognitive load that interferes with learning. Therefore, I incorporated this method into the study to further examine the relative germane cognitive load invested by learners. Students' scores on the Task Difficulty Rating Scale were used as M (mental effort) scores, while students' scores on the Factual Knowledge Test were used as P (performance) scores.

Factual Knowledge Test

Factual knowledge test was originally designed by Alien Rescue developers and was used in several previous studies to assess students' recall of declarative knowledge after completion of the Alien Rescue program (Williams, 1999). This instrument consists of 25 multiple choice items. It was used to gather information on the degree to which students acquired scientific concepts taught in Alien Rescue. The instrument was administered as a pretest and a post-test (see Appendix B). Data from this test were used in two ways. First, to answer research question 3, students' pre- and post-test scores were analyzed to identify if there was a significant difference among the three treatment conditions. Second, to answer part of research question 1, students' post-test scores on the factual knowledge test were used as performance scores (P) in the Instructional Efficiency formula $E = \frac{P - M}{\sqrt{2}}$. They were paired with students' task difficulty rating scores (M) to investigate the relative efficiency of the three treatment conditions: online database, paper-based database, and non-database condition.

Transfer Test

To answer the second research question, a transfer measure was used to assess students' cognitive skills. Versions of this instrument have been used in several previous studies (Williams, 1999; Pedersen, 2000). It was originally developed to assess learners' transfer of problem solving skills. Like Alien Rescue, this instrument provides students with a novel problem: the Salamander, an endangered fish species, is threatened by the growing pollution in Barton Creek. Students need to research and evaluate three locations and determine which would be the most feasible alternative habitat for the salamander. Two major Modifications were made to the instrument to allow examination of students' transfer of cognitive skills acquired through the use of database tools. First, the instrument was divided into four parts, each part focusing on a different set of cognitive skills. Second, the problem was simplified to include only one possible relocation possibility for salamander. Thus, instead of focusing on problem solving skill, this instrument focuses more on cognitive skills it targets to evaluate such as categorizing skills, differentiating skills, evaluating skill, and so forth. In addition, each part/task was assigned 25 points with a total of 100 points for the complete transfer measurement.

The first part of the measure focuses on learners' ability to categorize information. Students were given an email message from a biologist explaining the problem and asking for their help. The message described the salamander, its needs, and provides a brief description of the Barton Creek environment. Then, students were asked to analyze the email message, categorize the important information, and put them into a table format. To perform this task effectively, students had to determine what information they needed about Salamander and Barton Creek in order to solve the problem, discriminate the irrelevant information, collect and organize the relevant information, and generate appropriate categories to summarize the information. This task measures students' cognitive skills on classifying, categorizing, and differentiating.

To score students' responses, each of the category and its corresponding information was evaluated for its correctness. Since the previous versions of this measure did not have this task, an original rubric was constructed to assist a consistent scoring of students' responses. The range of possible scores is 0 to 25 points. Table 3.3 shows examples of how the rubric was used to score students' responses.

Table 3.3 Rubrics Used to Score Part 1 of the Transfer Measure

Range of Scores	Examples	Score Assigned	Rationale
Correctness of each category (0-2 points)	Food	2	An important category to help find a new home for salamander
	Earthworm/shrimp	1	The information is correct and essential to help find a new home for salamander. However, the category label is not appropriate.
	Body	0	Incorrect / irrelevant category
Correctness of the information under each category (0-3 points)	Salamanders eat earthworms and brine shrimp	3	Correct and complete information for the "food" category
	Salamanders eat earworms	1.5	Correct information. However, part of the information is missing
	They need to eat	0	No information is provided in this statement

In the second part of the measure, students were asked to further analyze the email message and to list three examples of the information they found in the email that did not contribute to the problem solving process. This task measures students' cognitive skills on differentiating, especially on differentiating the irrelevant information from the relevant information. To perform the task effectively, students had to determine what information was relevant to solve the problem, what information was irrelevant to solve the problem, and the connections between them.

To evaluate students' response, each correct example listed with detailed explanations was given full credit. Since this task has a total of 25 possible points, each of the three examples was assigned one third of the full possible point, which equaled to 8.33 points. Any correct example listed without explanation was give partial credit. And any incorrect example earned zero point.

In the third part of the transfer measure, a follow-up email message from the biologist was presented to students. In this message, the biologist described the LBJ habitat in details. Then, students were asked to identify two missing pieces of information from the second email message that were essential to make comparisons between the two email messages. This task measures students' cognitive skills on comparison. To perform this task, students needed to locate all the relevant information from both email messages, compare information from the first email message to information from the second email message, and find the missing information from the second message that did not match what is in the first message.

To evaluate students' response, each piece of missing information listed with accompanied explanations was given full credit. Since this task has a total of 25 possible points, each of the two pieces of information was assigned half of the full possible point, which equaled to 12.5 points. However, any information listed without accompanied explanation could only earn partial credit. And any incorrect answer would earn zero point.

In the final part of the transfer measure, students were asked to make a final recommendation on whether to relocate the salamander to lake LBJ or not. This final task measures students' cognitive skills on analyzing and evaluating. To perform this task, students had to analyze the information they had collected from both email messages, compare the information on salamander and lake LBJ, evaluate the feasibility to relocate salamander to lake LBJ, and made a final decision with supporting rationales. Since there are pros and cons of relocating salamander to the new location, there is no single correct answer to the problem. Students may have different decisions, yet all supported by valid arguments. Thus, a rubric was constructed to help raters score students' responses on this task and to eliminate possible subjective influence. The rubric was similar to the one used to assess students' problem solutions and rationales in several other studies (Williams, 1999, Pederson, 2000). Slight alternations were made so that the rubric would be more sensitive to evaluate cognitive skills. For example, in the previous rubric, there was a score on the overall persuasiveness of the rationale. In this study, this item was eliminated since it did not tie directly to students' evaluation skills. The score ranges from 0 to 25 points. Table 3.4 shows examples of how the rubric was used.

Table 3.4 Rubrics Used to Score the Part 4 of the Transfer Measure

Range of Scores	Examples	Score Assigned	Rationale
Inclusion of a topic sentence (0-1 points)	I think Lake LBJ is a good home for salamander	1	This is a correct and simple statement of the decision the student is defending.
	No topic sentence	0	There is no topic sentence on student's decision
Each supporting details (0-4 points)	Lake LBJ has shrimps that salamanders can eat.	4	Correct and complete details that pertinent the needs of salamander.
	Lake LBJ has bass and trouts that salamanders can eat.	0	Incorrect information.
Inclusion of each potential drawbacks (0-4 points)	One problem with Lake LBJ is that its water is not spring-fed.	4	Correct information is provided to acknowledge that the location may not be perfect.
	One problem with Lake LBJ is that it doesn't have earthworms that salamanders eat	0	Information provided is not a potential drawback of the location.

To ensure accurate and consistent scoring, students' responses on the transfer measure were scored by two raters, one of them was not aware of the treatment conditions. An orientation was also held for raters to discuss how to use the rubric and to score 10% of the responses together. Each of the remaining responses was scored by two raters. Discrepancies between the scores were identified and discussed between the two raters until the differences were solved. A copy of the instrument is provided in Appendix C.

Qualitative Data

Qualitative data was collected to gain a more comprehensive understanding of the research topics as well as to inform future research on how databases may be used to better support students' learning. Qualitative data was collected through interviews and observations.

Interviews

Students were asked to reflect on their learning experiences using the database tool. There are two parts to the interview. First, the interview focused on students' attitudes towards the use of the online database tool and the paper-based database tool. Some sample questions included "What do you think of the database tool?", "Is it helpful at all?" The second part of the interview focused on students' perceived cognitive load while using the database tool. Some sample questions include "Is the database tool hard to use? Why?", "Do you think the database tool slows you down?" Interviews were conducted with 50% of the students randomly chosen from each treatment condition at the end of the study. A list of the interview questions is included in Appendix D.

Observation

Observations were made to gather additional data on students' use of database tools, and how these tools affected students' problem-solving process in the Alien Rescue program. Sample data included the different behavior patterns and problem-solving processes among students in the three treatment conditions. For example, some questions the researcher kept in mind during the observation process included, "how do students in the database group perform research?", "How do students in the non-database group perform research?", "Do they use different research methods?"

The qualitative data was used to provide richer and more detailed information. It was used to verify the results from statistical data analysis.

PROCEDURES

The study was conducted over a four-week time period. Students used Alien Rescue in their regular science classes for 45 minutes daily on Dell laptop computers. In addition, students worked in groups of two or three on each laptop computer, depending on the total number of students in each class. During the first day of the study, students completed the factual knowledge measure (pre-test). Students then viewed the opening scenario of Alien Rescue together and briefly explored the environment. During the first week, students conducted general research in the Alien Rescue environment to gather information. Students in the paper-based database groups started using the paper-based database tool as soon as they started their research. They used their paper-based database tool daily to collect, organize, and evaluate information. At the beginning of the second week, students in the online database groups started using the online database tool. First, the researcher introduced the online database tool, followed by a discussion of the possible information categories needed in the database in order to solve the problem – finding homes for aliens. The researcher then worked together with the teachers to hold a 15-minute brainstorming session to help students generate an initial set of information categories such as atmosphere, temperature, water, and so forth. Over the three-week period, the online database group used the database tool daily in Alien Rescue. During the final 15 minutes of each class session, students were instructed to log into the online database to enter the data they had collected the day before and to make necessary comparisons. After the completion of Alien Rescue, the factual knowledge test and the transfer measure were administered to students. Task difficulty rating scale and interviews were also administered during the final three days of the study.

DATA ANALYSIS

In answering the first question, "Do the online and the paper-based database tools under investigation share learners' cognitive load by reducing extraneous cognitive load and increasing germane cognitive load? Does the online database tool share learners' cognitive load more effectively than the paper-based database tool?" task difficulty rating scale scores were used to calculate the mean amount of perceived mental effort. A one-way ANOVA was conducted to determine if scores on perceived mental effort differed by treatment conditions. A significantly higher mental effort score would indicate a higher cognitive load imposed on learners. Furthermore, instructional efficiency (E score) was also calculated for the three conditions: online database, paper-based database, and non-database. The E scores were then compared to predict whether the online database and paper-based database condition yielded significantly higher instructional efficiency than the non-database condition, and whether the online database condition yielded significantly higher instructional efficiency than the paper-based database condition.

In answering the second question, "How do the online and the paper-based database tools affect students' cognitive skills such as organizing, categorizing, analyzing, and evaluating? Does the online database tool facilitate learners' cognitive skill acquisition more effectively than the paper-based database tool?" students' scores on the transfer measure were used. A one-way ANOVA was calculated to determine if the scores were significantly different among the three treatment conditions, and whether the scores for the online database condition were significantly higher than the scores for the paper-based database condition. That is, a one-way ANOVA was calculated with the transfer measure scores of the three groups as the dependent variable, and the online database / paper database / non-database conditions as the independent variable.

In answering the third question, "Do the online and the paper-based database tool support students' performance in a hypermedia PBL environment? Does the online database tool improve learners' performance more effectively than the paper-based database tool?" students' scores on the factual knowledge measure were used. A one-way ANCOVA was calculated with the post-test (faculty knowledge test) scores of the three groups as the dependent variable, and the online database / paper database / non-database conditions as the independent variable. The pretest scores were used as a covariate.

Qualitative data were analyzed to gain a deeper understanding of the research topics as well as to inform future research directions. To analyze the qualitative data, interviews were first transcribed. The researcher followed the coding procedures for developing grounded theory that was proposed by Strauss and Corbin (1998). In open coding, the researcher 1) broke the data down into thought units, 2) grouped similar units according to their properties and dimensions, and 3) gave each group a name. During the coding process, the codes were refined and revised, and themes emerged. Then, the researcher sorted the data into categories and sub-categories according to their properties and dimensions. Patterns and relationships between themes and subcategories were examined to identify interesting findings. The results of the qualitative data analysis were used to support the statistical analysis discussed previously in this section and to inform future research.

Chapter 4: Results

This chapter presents the results of the study. The first part of the chapter illustrates the quantitative data and groups the information into the following categories: cognitive load, cognitive skills, and achievement. The second part of the chapter presents the qualitative data and organizes the information around themes, which emerged from the data analysis.

QUANTITATIVE RESULTS

Cognitive Load

In order to answer research question one, """Do the online and the paper-based database tools under investigation share learners' cognitive load by reducing extraneous cognitive load and increasing germane cognitive load? Does the online database tool share learners' cognitive load more effectively than the paper-based database tool?" An ANOVA analysis was performed, followed by an instructional efficiency analysis.

ANOVA Analysis

An ANOVA analysis was performed to compare mental effort scores (Task Difficulty Rating score) among the three treatment conditions. The results revealed a significant difference in mental effort scores among the groups, F (2, 94) = 6.33, $p <$ 0.003 ($MEAN_{\text{online database}} = 27.63$, $SD_{\text{online database}} = 6.28$; $MEAN_{\text{paper database}} = 30.77$, $SD_{\text{paper database}} = 5.24$; $MEAN_{\text{non-database}} = 33.08$, $SD_{\text{non-database}} = 7.23$) (see Table 4.1).

Table 4.1 ANOVA Analysis of Task Difficulty Rating Scale on Treatment Condition (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Between	501.22	2	250.61	6.33	0.003
Within	3721.77	94	39.59		
Total	4222.99	96			

In order to determine where the significant differences lied, post hoc analysis using Tukey's HSD test was conducted. The results indicated that online database groups scored significantly lower than the non-database groups, $p < 0.1$. However, there was no significant difference between online database and paper-based database groups. There was also no significant difference between paper-based database and non-database groups. To further determine the type of cognitive load (extraneous or germane) imposed on students, instructional efficiency analysis was conducted as follows.

Instructional Efficiency Analysis

To further determine the effects of mental effort (cognitive load) on learning, an instructional efficiency (E) score was calculated for each condition: online database, paper-based database, and non-database, using the Task Difficulty Rating scores and the Performance scores. Both scores were transformed into standardized *z* scores. Then, the means of these z-scores for each condition were combined into the following efficiency formula:

$$E = \frac{P - M}{\sqrt{2}}$$

According to this expression, E is positive if $P - M > 0$, negative if $P - M < 0$. The greater the value of E, the more efficient is the instructional condition. Table 4.2 shows the mean for normalized (Z) mental effort and performance scores and the instructional efficiency (E) scores for each condition.

Table 4.2 Normalized (Z) Scores and Instructional Efficiency (E) Scores for Mental Effort and Performance

Treatment Conditions					
Online Database		Paper-Based Database		Non-Database	
Z (mean) (mental effort, performance)	E (efficiency)	Z (mean) (mental effort, performance)	E (efficiency)	Z (mean) (mental effort, performance)	E (efficiency)
-0.38; 0.76	0.81	0.09; -0.39	-0.33	0.44;-0.63	-0.76

The online database group had a positive E score of 0.81, which indicated that a relatively low mental effort was followed by a relatively high performance. Both the non-database group and the paper-based database group had negative E scores, which indicated that a relatively high mental effort is followed by a relatively low performance. However, the paper-based database group had a higher E score (-0.33) than the non-database group (-0.76). Thus, the online database condition was instructionally more efficient than the paper-based database condition, and the paper-based database condition was instructionally more efficient than the non-database condition. Figure 4.3 further summarizes the relationships among mental effort, performance, and instructional efficiency for each condition group.

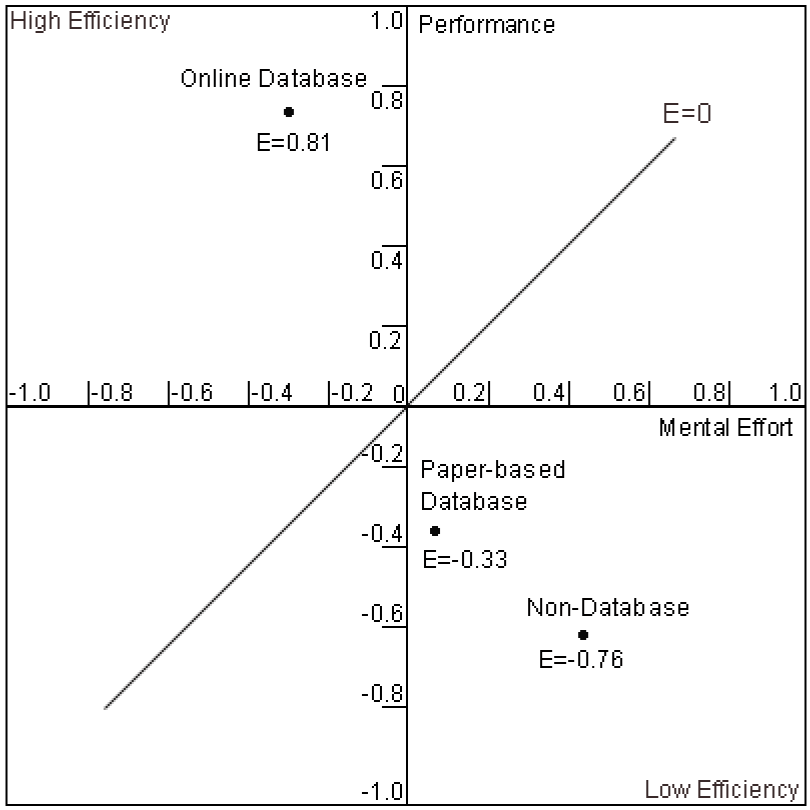


Fig. 4.3 Relative instructional efficiency for each condition

Transfer of Cognitive Skills

In order to answer research question two, “How do the online and the paper-based database tools affect students’ cognitive skills such as organizing, categorizing, analyzing, and evaluating? Does the online database tool facilitate learners’ cognitive skill acquisition more effectively than the paper-based database tool?" a one-way ANOVA was conducted to compare transfer measure (cognitive skill measure) scores among three treatment conditions. The results revealed a significant difference in transfer measure scores among the groups, $F(2, 94) = 30.49$, $p < 0.0001$. ($MEAN_{online\ database} = 49.78$, $SD_{online\ database} = 15.1$; $MEAN_{paper\ database} = 27.25$, $SD_{paper\ database} = 11.71$; $MEAN_{non\text{-}database} = 27.28$, $SD_{non\text{-}database} = 14.21$)(See Table 4.4).

Table 4.4 ANOVA Analysis of Cognitive Skill Transfer Measure on Treatment Conditions (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Between	11715.32	2	5857.6	30.49	<0.0001
Within	18059.84	94	192.13		
Total	29775.16	96			

To determine where the significant differences lied, post hoc analysis using Tukey's HSD test was performed. The results showed that online database groups scored significantly higher than the paper-based database groups ($p < .01$) and the non-database groups ($p < .01$). However, there was no significant difference between paper-based database groups and non-database groups.

To gain a deeper understanding of the impact of the treatment conditions on different types of cognitive skills, follow-up ANOVAs were conducted on the first, second, and fourth part of the transfer measure, which focused on categorizing, differentiating, and analyzing / evaluating skills respectively. Since a large number of students left the third part of the transfer measure blank, it was excluded from the data analysis. All three ANOVA analyses returned significant differences. Table 4.5 summarizes these analyses.

Table 4.5 ANOVA Analysis for Categorizing, Differentiating, and Analyzing/Evaluating on Treatment Conditions (online database / paper-based database / non-database)

	Treatment Conditions			F	P
	Online Database	Paper-Based Database	Non-Database		
Categorizing (Score range 0 – 25)				18.52	0.0001
Mean	17.72	11.13	10.66		
SD	3.80	5.26	7.08		
N	38	30	29		
Differentiating (Score range 0 – 25)				12.19	0.0001
Mean	15.80	8.28	9.19		
SD	5.37	7.94	7.58		
N	38	30	29		
Analyzing/Evaluating (Score range 0 – 25)				9.79	0.0001
Mean	11.64	7.5	6.74		
SD	5.96	3.60	4.69		
N	38	30	29		

Tukey's HSD tests were also performed following each ANOVA analysis. The results showed that online database groups scored significantly higher than paper-based database groups and non-database groups on all three cognitive skill categories. However, there was no significant difference between paper-based database groups and non-database groups on any cognitive skill category.

Achievement

In order to answer the third research question, "Do the online and the paper-based database tool support students' performance in a hypermedia PBL environment? Does the online database tool improve learners' performance more effectively than the paper-based database tool?" a one-way analysis of covariance (ANCOVA) was calculated with the post-test (Factual Knowledge Test) data as the dependent variable and the pre-test data as the covariate.

In order to determine whether the homogeneity of regression assumption was met, a test for interactions between covariates and factors (Test for Homogeneity of Regressions) was conducted. The results showed that the between (group * pre-test) effect had a small *F* statistic (0.43) and a large significance value (0.65). Table 4.6 shows the results of the test.

Table 4.6 Test for homogeneity of regressions

Source	**SS**	**DF**	**MS**	**F**	**P**
Between Regressions	5.81	2	2.91	0.43	<0.65
Remainder	620.55	91	6.82		
Adjusted Error	626.36	93			

Since the significance level was greater than .05, the homogeneity of regression assumption had been met. The researcher then proceeded with the ANCOVA analysis. The ANCOVA results revealed a significant difference in achievement (Factual Knowledge Test) scores among the groups, $F(2, 93) = 26.51$, $p < 0.0001$ (MEAN $_{\text{online database}}$ = 16.29, ADJUSTED MEAN $_{\text{online database}}$ = 15.79; MEAN $_{\text{paper database}}$ = 11.93, ADJUSTED MEAN $_{\text{paper database}}$ = 12.28; MEAN $_{\text{non-database}}$ = 11, ADJUSTED MEAN $_{\text{non-database}}$ = 11.29) (see Table 4.8).

Table 4.7 ANCOVA Analysis of Factual Knowledge Test Scores on Treatment Conditions (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Adjusted Means	357.13	2	178.57	26.51	<0.0001
Adjusted Error	626.36	93	6.74		
Adjusted Total	983.49	95			

To determine where the significant differences lied, post hoc pairwise comparisons were made using Bonferroni correction method. The results indicated that online database groups scored significantly higher than both non-database groups ($p < .0001$) and paper-based database groups ($p < .0001$). However, there was no significance difference between non-database groups and paper-based database groups.

ALTERNATIVE QUANTITATIVE ANALYSIS RESULTS

Due to administrative and convenience reasons, one of the classes in the online database treatment condition consisted of all math excel students. To control this variable, the researcher decided to modify the original data analysis arrangement by doing an alternative quantitative analysis, which excluded the math excel class as well as the two other classes taught by the same instructor. Thus, the following analysis only took into account of three classes (randomly assigned to three conditions) that were comparable in students' abilities and were taught by the same instructor. However, the exact same data analysis procedure was used.

Cognitive Load

An ANOVA analysis was performed followed by an instructional efficiency analysis to answer research question one on cognitive load.

ANOVA Analysis

An ANOVA analysis was performed to compare mental effort scores (Task Difficulty Rating score) among the three treatment conditions. The results showed that there was no significant difference in mental effort scores among the groups, $F(2, 49) = 1.11$, $p < 0.34$. (MEAN $_{\text{online database}} = 28.45$, SD $_{\text{online database}} = 6.64$; MEAN $_{\text{paper database}} = 31$, SD $_{\text{paper database}} = 4.4$; MEAN $_{\text{non-database}} = 31.19$, SD $_{\text{non-database}} = 7.19$)(See Table 4.8).

Table 4.8 Alternative ANOVA Analysis of Task Difficulty Rating Scale on Treatment Condition (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Between	86.30	2	43.15	1.11	0.34
Within	1905.39	49	38.89		
Total	1991.69	51			

Instructional Efficiency Analysis

To further determine the effects of mental effort (cognitive load) on learning, an instructional efficiency (E) score was calculated for each condition: online database, paper-based database, and non-database, using the Task Difficulty Rating scores and the Performance scores.

Table 4.9 Alternative Analysis of Normalized (*Z*) Scores and Instructional Efficiency (*E*) Scores for Mental Effort and Performance

Group					
Online Database		Paper-Based Database		Non-Database	
Z (mean) (mental effort, performance)	E (efficiency)	Z (mean) (mental effort, performance)	E (efficiency)	Z (mean) (mental effort, performance)	E (efficiency)
-0.28; 0.65	0.66	0.14; -0.15	-0.20	0.17;-0.64	-0.58

The online database group had a positive *E* score of 0.66, which indicated that a relatively low mental effort was followed by a relatively high performance. Both the non-database group and the paper-based database group had negative *E* scores, which indicated that a relatively high mental effort was followed by a relatively low performance. However, the paper-based database group had a higher *E* score (-0.20) than the non-database group (-0.58). Thus, the online database condition was instructionally more efficient than the paper-based database condition, and the paper-based database condition was instructionally more efficient than the non-database condition. Figure 4.10 further summarizes the relationship among mental effort, performance, and instructional efficiency for each condition group.

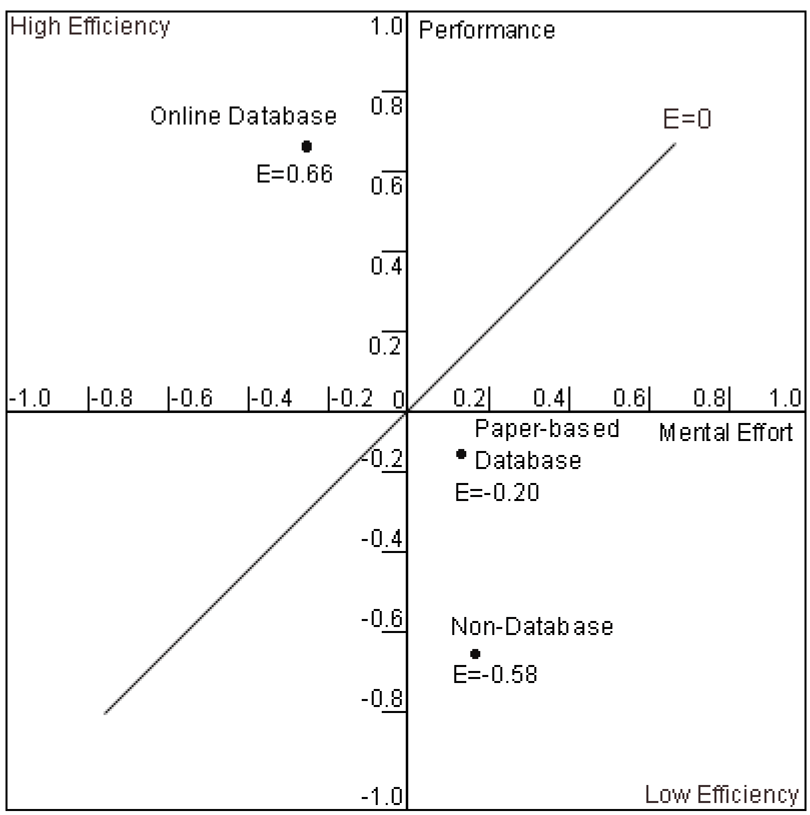


Fig. 4.10 Alternative Analysis of Relative instructional efficiency for each condition

Transfer of Cognitive Skills

In order to answer research question two on cognitive skills, a one-way ANOVA was conducted to compare transfer measure (cognitive skill measure) scores among the three treatment conditions. The results revealed a significant difference in transfer measure scores among the groups, $F(2, 49) = 8.79$, $p < 0.001$. (MEAN $_{\text{online database}}$ = 44.4, SD $_{\text{online database}}$ = 17.04; MEAN $_{\text{paper database}}$ = 27.28, SD $_{\text{paper database}}$ = 12.86; MEAN $_{\text{non-database}}$ = 25.25, SD $_{\text{non-database}}$ = 15.02)(See Table 4.8).

Table 4.10 ANOVA Analysis of Cognitive Skill Transfer Measure on Treatment Condition (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Between	4080.46	2	2040.23	8.79	<0.001
Within	11377.10	49	232.19		
Total	15457.56	51			

To determine where the significant differences lied, post hoc analysis using Tukey's HSD test was performed. The results showed that online database group scored significantly higher than the paper-based database group ($p < .01$) and the non-database group ($p < .01$). However, there was no significant difference between the paper-based database group and the non-database group.

To gain a deeper understanding of the impact of the treatment conditions on different types of cognitive skills, follow-up ANOVAs were conducted on three parts of the transfer measure, which focused on categorizing, differentiating, and analyzing /

evaluating skills respectively. All three ANOVA analyses returned significant differences (see Table 4.11).

Table 4.11 ANOVA Analysis for Categorizing, Differentiating, and Analyzing/Evaluating on Treatment Conditions (online database / paper-based database / non-database)

	Treatment Conditions				
	Online Database	Paper-Based Database	Non-Database	F	P
Categorizing				13.78	0.0001
Mean	16.73	10.38	8.5		
SD	4.58	5.69	4.68		
N	20	16	16		
Differentiating				4.34	0.02
Mean	14.3	8.78	8		
SD	5.96	7.24	8.13		
N	20	16	16		
Analyzing/Evaluating				3.64	0.03
Mean	11.38	7.5	7.5		
SD	6.95	2.74	3.76		
N	20	16	16		

Tukey's HSD tests were also performed following each ANOVA analysis. The results showed that online database group scored significantly higher than the paper-based database group and the non-database group on categorizing skill categories. The results also revealed a significant difference between online database and non-database group on differentiating skill categories. In addition, the difference between the online database and non-database group approached the level of significance on analyzing/evaluating skill category. Finally, the online database group tended to score significantly better than the paper-based database group on differentiating and analyzing/evaluating skill categories.

Achievement

To answer the third research question, a one-way analysis of covariance (ANCOVA) was calculated with the post-test (Factual Knowledge Test) data as the dependent variable and the pre-test data as the covariate.

In order to determine whether the homogeneity of regression assumption was met, a test for interactions between covariates and factors (Test for Homogeneity of Regressions) was conducted. The results showed that the between (group * pre-test) effect had a small *F* statistic (0.04) and a large significance value (0.96). Table 4.12 shows the results of the test.

Table 4.12 Test for homogeneity of regressions

Source	**SS**	**DF**	**MS**	**F**	**P**
Between Regressions	0.47	2	0.23	0.04	<0.96
Remainder	287.85	46	6.26		
Adjusted Error	288.31	48			

Since the significance level was greater than .05, the homogeneity of regression assumption had been met. The researcher then proceeded with the ANCOVA. The ANCOVA results revealed a significant difference in achievement (Factual Knowledge Test) scores among the groups, $F(2, 93) = 26.51$, $p < 0.0001$ (MEAN $_{\text{online database}} = 15.4$, ADJUSTED MEAN $_{\text{online database}} = 14.84$; MEAN $_{\text{paper database}} = 12.38$, ADJUSTED

MEAN $_{\text{paper database}}$ = 12.61; MEAN $_{\text{non-database}}$ = 10.43, ADJUSTED MEAN $_{\text{non-database}}$ = 10.91) (see Table 4.13).

Table 4.13 ANCOVA Analysis of Factual Knowledge Test Scores on Treatment Conditions (online database / paper-based database / non-database)

Source	**SS**	**DF**	**MS**	**F**	**P**
Adjusted Means	133.15	2	66.58	11.08	<0.0001
Adjusted Error	288.31	48	6.01		
Adjusted Total	421.46	50			

Post hoc pairwise comparisons were made using Bonferroni correction method to determine where the significance lied. The results showed that the online database group scored significantly higher than both the paper-based database group ($p < .0001$) and the non-database group ($p < .03$). However, there was no significance difference between the non-database group and the paper-based database group.

QUALITATIVE RESULTS

The qualitative data were examined in order to gain a more robust and deeper understanding of students' attitudes towards the online database tool, students' behavior pattern, and students' cognitive processes during the use of the tool. Most students' responses toward the use of the online database tool were very positive. Seven themes emerged from interview data: organization tool, research method, share/add cognitive load, ease/hard of use, preference for paper-based notes, insufficient use of paper-based database tool, management issues. Each of these themes was discussed below.

Organization Tool

The interview data revealed that both the online database tool and the paper-based database tool helped student organize information. Students stated that the online database tool helped them stay organized, "It really helped, so we don't have to write down on different piece of paper and keep that paper". Students who used the paper-based database tool also commented that "I put them all in the notes [paper charts] and I compare the two. I organize them in temperature, habitat... and compare them in paper". Several students using the online database tool specifically pointed out that the tool helped them create information categories to store research data, "We broke information down, just the key things…we put them in the database…"

Research Method

Some students in the online database group mentioned the usefulness of the database tool to help them do research in Alien Rescue. They pointed out two major ways the database tool supported their research. The first was the comparison support. The online database tool helped students make faster and more efficient comparisons [between aliens and planets], "I just choose a alien and a planet, then click 'compare' to see what they have in common". Second, the online database tool also helped with the creation of probes. According to students, the database tool helped them list conditions of each alien and planet so that they could compare and locate possible matches. This, in turn, helped them build more efficient probes so that they could find information and solve the problems faster, "we use information in our database to build the probes. We show Ms. Squires [instructor] our database so she can give us the code [to launch probes]. Most times, after we send the probe, it helps us find the aliens".

Share/Add Cognitive Load

Many students in the online database group indicated that the tool helped them store information so that they didn't have to memorize them, "it helps you remember all the information about it". This finding is consistent with Lajoie's (1993) definition of cognitive tools. The second type of cognitive tool, as defined by Lajoie, shares the cognitive load by providing support for lower level cognitive skills such as memorization so that resources are left over for higher order thinking skills. It also supported researcher's hypothesis that the online database tool helped share learners' cognitive load.

However, some statements also showed that the database tool added extra burden to learners' cognitive load, "It's kind of hard to start first". A couple of students complained that, "I didn't really get to use it. I only got to it twice maybe, 'cause we have to finish research, and we don't have time to use it".

Ease / Hard of Use

Students found both the online database tool and the paper-based database tool fairly easy to use, "It's easy. It helps. If we don't use it, it would be a lot harder." Especially since the online database tool saved students notes in electronic format, "we didn't have to write on paper and keep track of it". However, students using the online database tool pointed out that the tool was hard to start with, "It's kind of hard to start first. But when you get to the middle of it, it's a lot easier," "it took a while to fill out everything".

Preference for Paper-Based Notes

Although most students using the online database tool like the fact that everything was in electronic format so that it was easy to store and retrieve information, a couple of students complained about the online database tool and showed preferences to take notes and organize them on paper, "I don't like it. We wrote everything down in the notebook. It's easier," "we didn't use the database tool. We wrote everything down on paper, we don't want to enter it in the database again". These students showed a clear preference for paper-based notes and preferred writing and reading on paper to typing and reading on computers.

Insufficient Use of Paper-Based Database Tool

Students' response to the use of the paper-based database tool was rather mixed. Surprisingly, a number of students interviewed from the paper-based database group indicated that they did not actually use the paper-based database tool (paper charts) that much. In regards to the question about how they used the tool, some students stated that "not much", "we didn't really get to use it that much". They simply used their notes to do research in AR. However, others did use the tool and found it useful in Alien Rescue, "yes, it really helped us", "we use the elimination charts [in the paper-based database tool] to do that [comparison]. And we do the matching [using the charts]".

Management Issue

A couple of management issues related to the online database tool emerged from the data: typing problems, management of two systems.

A couple of students complained about the amount of typing required in order to use the database tool, "if you like typing, you'll love it. I don't like typing", "I think it's kind of hard to type in all the information, but if you do it, if you start off using it, it's a lot easier".

Several students also complained that they had to toggle between the online database tool and Alien Rescue, which was quite time consuming and hard to manage, "It takes some time to go back and forth between the two". The same issue came up from the pilot study as well. However, due to lack of programming support, the researcher was not able to integrate the database tool into Alien Rescue at this time.

Chapter 5: Discussion

The results of this study showed that the online database tool impacted learning in a number of ways. The discussion of the findings was based on the results from the original quantitative analysis, the alternative quantitative analysis, and qualitative analysis. The first part of the chapter revolved around the three specific research questions. The latter part of the chapter provided a general discussion of the future research directions.

COGNITIVE LOAD

Overall Mental Effort (Cognitive Load)

The researcher's original hypothesis was that database tools functioned as cognitive tools to share learners' cognitive load. First, students could write or type their research data into the online or paper-based databases in an organized manner. Thus, they did not have to memorize that information, which in turn helped reduce cognitive load. Second, online database tool offered a comparison feature that allowed students to locate and compare various pieces of information quickly and to make efficient comparisons. Thus, the online database tool should be able to share learners' cognitive load more efficiently than the paper-based database tool. The results, however; only supported part of the hypothesis.

The original quantitative analysis on Task Difficulty Scale of all six groups revealed that the online database groups had significantly lower mental effort than the non-database groups. However, there was no significant difference between online database groups and paper-based database groups. There was also no significant difference between paper-based database groups and non-database groups. Furthermore, the alternative analysis on three groups of students indicated that there was no significant difference on students' perceived mental effort among the online database group, the paper-based database group, and the non-database group. It suggested that neither the online database tool nor the paper-based database tool reduce the total amount of cognitive load imposed on learners.

Thus, it is rather obvious that none of the database tools investigated in this study contributed much to reduce the overall cognitive load imposed on learners. This result may be due to the fact that students had to master yet another tool besides Alien Rescue. The learning and use of database tools imposed additional cognitive load on learners. Thus, even though the tools relieved students from intensive memorization, the overall cognitive load imposed on learners remained unchanged.

In addition, there was a discrepancy between the two analyses on Task Difficulty Rating Scale scores. The alternative analysis revealed no significance results, while the original analysis revealed a significant difference between online database and non-database groups. This result may be due to the fact that one of the online database groups in the original analysis consisted of all high-ability students. It suggested a possible influence of individual differences on cognitive load. It seemed that high-ability students perceived the database tool as easier than the average-ability students did. Thus, the online database tool imposed less cognitive load on high-ability students and therefore benefited them more. However, more investigation is needed to confirm this hypothesis.

Types of Cognitive Load

Instructional efficiency scores helped the researcher further analyze and distinguish the type of cognitive load imposed by the database tools and whether they contributed to or interfered with learning. Results from the original quantitative analysis and the alternative quantitative analysis were rather comparable on *E* scores. The online database groups had the highest *E* (Instructional Efficiency) scores in both analysis (0.81, 0.66); the non-database groups had the lowest *E* scores (-0.76, -0.58); and the paper-based database groups fell in the middle (-0.33, -0.20).

Not surprisingly, non-database groups had the lowest, negative *E* scores, which indicated a fairly low performance, especially since their mental effort scores were similar to those of the two database groups. Thus, most of the cognitive load imposed on learners from non-database groups was extraneous cognitive load, which interfered with rather than contributed to learning. However, it was unexpected to find that paper-based database groups also had negative *E* scores, which were much lower than online database groups. Since the two database groups had comparable mental effort scores, this result indicated that online database groups had a higher percentage of germane cognitive load, which contributed to learning. Since the online database tool helped students organize information, make connections among concepts, and draw inferences, students' attention was redirected to cognitive processes that were directly relevant to the construction of schema. Thus, even though the online database tool still imposed cognitive load on learners, such load was germane cognitive load that actually enhanced learning. On the other hand, paper-based database groups had a lower percentage of germane cognitive load. Although the paper-based database tool was originally built to mimic most of the functions offered by the online database tool, it was not as efficient as the online database tool instructionally. For example, while doing information comparisons to find matching planets for aliens, students using the online database tool could flip through information tables very quickly and tried a large number of possible matches in a rather short amount of time using built-in queries. However, student using the paper-based database tool had to manually locate various information tables; flipped back and forth between pages to compare information; and relied on the elimination chart to record and memorize possible matches. A large portion of the cognitive load imposed on learners was extraneous cognitive load that interfered with learning.

In addition, it is rather noticeable that there was a larger difference among students' E scores in the original qualitative analysis than the alternative analysis (see Table 5.1).

Table 5.1 E Scores Comparison (Original Analysis vs. Alternative Analysis)

	Original Analysis (six groups)	Alternative Analysis (three groups)
Online Database Groups (E score)	0.81	0.66

Paper-based Database Groups (E score)	-0.33	-0.20
Non-Database Groups (E score)	-0.76	-0.58

This result suggested a possible influence of individual differences on cognitive load. High ability students using the online database tool yielded the highest instructional efficiency. As I discussed earlier, the online database tool imposed less cognitive load on learners. The combination of lower cognitive load and higher achievement scores implied that high-ability students benefited more from the online database tool than the average-ability students did.

The qualitative data analysis also supported the above results. Students pointed out that the online database tool helped them store information so that they didn't have to memorize them. However, they also mentioned that the online database tool was hard to start with, even though "it makes things much easier once you are in the middle of it". This comment supported the quantitative results that the online database tool did not reduce the total amount of cognitive load. Rather, it reduced the amount of extraneous cognitive load and increased the amount of germane cognitive load.

Taken together, these findings indicated that database tools impacted the type of cognitive load imposed on learners. Specifically, the online database tool helped to reduce the amount of extraneous cognitive load and increase the germane cognitive load that enhances learning. Thus, the total amount of cognitive load imposed on learners remained the same, while the percentage of extraneous cognitive load and germane cognitive load changed. The paper-based database tool, however; did not contribute much to increase the germane cognitive load. It yielded much lower *E* scores than the online database tool (-0.33 vs. 0.81; -0.20 vs. 0.66). Even though paper-based database groups had higher *E* scores than non-database groups, the differences were rather small (-0.33 vs. -0.76; -0.20 vs. -0.58). In addition, since the scores were negative, they indicated that paper-based database groups had low instructional efficiency.

Another factor to consider is that a number of students in paper-based database groups did not make full use of the tool due to management and personal preference reasons. Qualitative data analysis revealed that some students did not use the elimination chart, which was the most important part of the paper-based database tool. Thus, the *E* scores obtained from the study on paper-based database groups might not be an accurate representation. In addition, individual difference might be another factor that impacted cognitive load. Results from both quantitative analyses (original & alternative) suggested that the online database tool benefited high-ability students more than average-ability students. Further research is needed to determine the effects of paper-based database tool and individual differences on cognitive load.

COGNITIVE SKILLS

Results from both quantitative analyses (original & alternative) regarding the transfer of cognitive skills indicated that online database groups scored significantly higher than paper-based database groups and non-database groups. Nevertheless, there was no significant difference between paper-based database groups and non-database groups. This finding suggested that the online database tool facilitate learners' acquisition of cognitive skills, which, according to major theories about thinking (Ericsson & Hastie, 1994), is an important variable that contributes to learning and accounts for the largest individual differences in performance. To gain a deeper understanding of the impact of the treatment conditions on different types of cognitive skills, results from follow-up analysis on three different parts of the transfer measure were also taken into account.

Categorizing Skills

The first part of the transfer measure consisted of questions regarding categorizing skills. Results from both the original and the alternative quantitative analyses revealed that online database groups scored significantly higher than paper-based groups and non-database groups on questions regarding categorizing skills. There was also no significant difference between paper-based database groups and non-database groups.

According to Bloom's taxonomy, categorizing is a higher-order cognitive skill that helps learners break down, organize, and structure information so that inter-relationships may be identified. It is an essential cognitive skill that contributes to analyzing and synthesizing. The online database tool offered learners a tool to enter and modify information categories. To perform this task, learners had to gather the relevant information, break them down, and organize them into categories. Once the categories were created and entered into the database, learners could then sort and organize future information under each category. However, the paper-based database tool did not facilitate learners' acquisition of categorizing skills. This might due to the specific design of the paper-based database tool. To help students take notes more efficiently into the paper-based database, the two teachers decided to provide students with most major information categories needed in Alien Rescue. Consequently, students did not need to create their own categories. Instead, they simply gathered the information and put them under relevant categories. The lack of practice on creating and modifying categories might contribute to the fact that students using the paper-based database tool did not acquire sufficient categorizing skills.

Finally, non-database groups did not have access to any organizational tools that supported the creation of categories. They did not have any opportunities to practice categorizing skills and thus did not acquire them.

Differentiating Skills

The second part of the transfer measure consisted of questions regarding differentiating skills. The results from the original analysis indicated that online database groups scored significantly higher than non-database groups and paper-based database groups on differentiating skills. There was also no significant difference between paper-based database groups and non-database groups. The results from the alternative analysis were comparable with the original analysis.

According to Bloom's taxonomy, differentiating is a higher-order cognitive skill that helps learners break down the information into elements and identify the relationships among the different elements. For example, while solving a problem, learners need to differentiate the irrelevant information from the relevant information so that they do not have to waste time memorizing and analyzing the unrelated information. Both the online database tool and the paper-based database tool required students to enter information into relevant categories. To perform this task, students had to search through the enormous amount of information in Alien Rescue; locate the relevant information; and discard the irrelevant information. This repetitive process should facilitate students' acquisition of differentiating skills. The results from both analyses suggested that the online database tool facilitate learners' differentiating skills. Yet, the paper-based database tool facilitated the acquisition of differentiating skills to a less extent. This finding might due to the design of the paper-based database tool that all information categories were pre-created for students. Students did not need to think hard to differentiate information, create categories, and organize information accordingly. Rather, they could simply locate the relevant information based on the pre-created categories. The lack of practice on differentiating skills contributed to the results that students using the paper-based database tool did not acquire sufficient differentiating skills.

Additionally, the non-database group had no access to any database tools. Most students simply used pieces of paper to take notes randomly here and there from Alien

Rescue (the notebook tool in Alien Rescue was not used due to technical considerations). Researcher's observation revealed that only when students started building probes, did they notice that some of their notes were totally irrelevant to the problem. However, at that time, they did not have enough time to go back and redo the research. Thus, students did not have enough opportunities to practice differentiating skills.

Analyzing / Evaluating Skills

The last part of the transfer measure consisted of questions related to analyzing and evaluating skills. The results from the original analysis showed that online database groups scored significantly higher than paper-based groups and non-database groups. However, the results from the alternative analysis were rather different. It revealed that the difference among the online database group, the paper-based database group, and the non-database group did not reach the level of significance, even though there was a trend towards significance.

Based on researcher's hypothesis, learners using the online database tool had to perform queries, analyze and evaluate the query results, and develop plans for future data collection and problem solving. Thus, the online database tool should facilitate learners' acquisition of analyzing and evaluating skills. One possible explanation to the results from the alternative analysis was that students did not have to create their own queries in the database tool. In order to make the online database tool simple and easy to use so that less cognitive load was imposed on learners, the researcher decided to create a built-in comparison query. Thus, to compare and evaluate information in the database, students only needed to choose the Alien and the planet they wanted to compare, and click the "compare" button. This function reduced students' cognitive load, while at the same time provided a lazy way for students to analyze information so that students might not think as hard as they should be. This built-in query helped students solve problems faster and more efficiently in Alien Rescue. However, it might also interfere with students' acquisition of analyzing and evaluating skills. One other possible explanation to the different results between the two analyses was individual differences. Since one of the online database groups in the original analysis was composed of all high-ability students, it yielded significantly higher scores. The results might suggest that high-ability students benefit more from the online database tool.

Taken together, these results indicated that the online database tool facilitated learners' acquisition of categorizing and differentiating skills. However, the paper-based database tool facilitated learners' acquisition of categorizing and differentiating skills to a much lesser extent. In addition, the study returned mixed results on the acquisition of analyzing/evaluating skills. Both the online database and paper-based database tools did not facilitate the acquisition of analyzing/evaluating skills for average-ability students. However, the online database tool did facilitate the acquisition of those skills for high-ability students. The non-significant results for the paper-based database tool might partly due to the specific design of the tool under investigation in this study. Individual difference might also play an important role in the acquisition of those cognitive skills. Further investigation is needed to take into account of individual differences, and to confirm the results using more standardized type of database tools.

ACHIEVEMENT

The results of the Factual Knowledge Measure from both original and alternative analyses showed that online database groups scored significantly higher than paper-based database groups and non-database groups. In addition, there was no significant difference between paper-based database groups and non-database groups.

This finding is consistent with researcher's hypothesis that the online database tool supported and enhanced learners' performance in a hypermedia PBL environment. The online database provided students an efficient and easy-to-use tool that helped them organize and structure information, share learners' cognitive load, and facilitate the acquisition of cognitive skills. Thus, learners were able to reach higher achievements than those who did not have access to the tools.

However, the results also suggested that the paper-based database tool did not enhance learners' performance in a hypermedia PBL environment. Although this finding was inconsistent with researcher's hypothesis, it was not surprising since analyses on both cognitive load and cognitive skills indicated that the paper-based database tool was less effective than the online database tool on sharing cognitive load and facilitating the acquisition of cognitive skills. However, as mentioned before, this result might be partly due to the specific design of the paper-based database tool, which leads to less practice on certain cognitive skills. Also, the qualitative data revealed that some participants did not make full use of the paper-based database tool, which might also contaminate the data. Therefore, follow-up study is needed to control this matter so that we can either confirm or reject this finding.

CONCLUSIONS

This study focused on the effects of databases as cognitive tools to support learning. It is exploratory to some extent since there is a rather limited literature base on databases as cognitive tools to support learning in hypermedia PBL learning environments. It begins to provide some insights into how databases may be used to impact various aspects of learning.

The findings in this study are consistent with Jonassen & Reeves' (1996) prediction that databases can function as cognitive tools because of their organized and defined nature. Specifically, the results indicated that the online (computerized) database tool under investigation in this study functioned as a cognitive tool in three different ways. Firstly, the online database tool had great impact on the nature of cognitive load imposed on learners. It did not reduce the total amount of cognitive load. Rather, it helped to reduce the amount of extraneous cognitive load and to increase the germane cognitive load that facilitates learning. Secondly, the online database tool facilitated learners' acquisition of higher order cognitive and thinking skills such as categorizing and differentiating. However, it only supported the acquisition of analyzing and evaluating skills for high-ability students but not for average-ability students. This finding is inconsistent with Watson and Strudler's (1988-89) prediction that the construction and use of databases facilitated the acquisition of analyzing and evaluating skills. Further investigation is needed to verify this finding. And finally, the online database tool supported and enhanced learners' performance in hypermedia PBL environments such as Alien Rescue.

The general effectiveness of the online database functioned as cognitive tools in this study suggested that online databases maybe designed into classroom activities to help learners organize information, share cognitive load, acquire higher order cognitive skills, and perform better.

However, the paper-based database tool, another database tool under investigation in this study, did not function effectively as a cognitive tool. Several factors may contribute to this result such as pre-created categories, individual differences, learning style, and the level of scaffolding. Further examination is necessary to investigate why the paper-based database tool is not as effective as the online database tool, and whether paper-based databases can indeed function as cognitive tools.

This study just begins the exploration of how databases can function as cognitive tool to support learning. The findings are subject to verification through replicated studies. Future research is also need to get a deeper, more completed and accurate understanding of the nature of databases and how they can function as cognitive tools. Some suggested future research directions are discussed in the following section.

FUTURE RESEARCH

The potential of databases as cognitive tools for teaching and learning is only beginning to be explored. The findings of this study provide only a small portion of the knowledge which may help us to fulfill this potential. More comprehensive and continuous research effort is needed to explore the full potential of various types of databases as cognitive tools in a variety of learning environment.

A concern surfaced during the data analysis is that neither the online database tool nor the paper-based database tool facilitated average-ability learners' acquisition of analyzing and evaluating skills. In order to control learners' cognitive load, the researcher modified the traditional database and made it easier to use. This simplified version of database eased learners' cognitive load; however, at the same time provided little opportunities for learners to practice and acquire analyzing and evaluating skills. Future research should consider the design of database tools and try to keep as much features of a traditional database as possible. On the other hand, databases should not be too complicated, which in turn may impose additional extraneous cognitive load on learners. A balance between cognitive load and database complexity should be maintained.

Another concern is that a number of students in the paper-based database groups stated that they did not make full use of the database tool. Since it was the first time we included the paper-based database tool into Alien Rescue, the best way to manage students' use of the tool was not yet determined. Both the researcher and the instructors were led mostly by their instinct and past experience on this matter. Learning from this study, future research must provide guidelines to instructors on how to manage students' use of the paper-based database tool and further investigate the impact of paper-based databases on learning.

In addition, it is interesting to find out that the online database tool benefits high-ability students more than the average-ability students. Although this study was not designed to assess the impact of individual differences on learning while using database tools, future research may be done to further investigate how students with high-ability, average-ability, and low-ability may benefit from database tools.

A final interesting avenue for future research is to investigate how students with different learning styles use database tools. For example, a couple of students indicated that they did not like to use the online database tool. Rather, they prefer to use paper and pencil to take notes and organize their research data. Future research may use both quantitative measure of achievements and attitudes and qualitative data to describe how students with different learning styles learn using database tools.

EDUCATIONAL IMPLICATIONS

The findings of this study, although only provide us a starting point to explore the full potential of databases as cognitive tools, have some important educational implications.

The effectiveness of the online database tool to share cognitive load, facilitate cognitive skills acquisition, and improve performance suggest that customized computerized databases maybe built into middle school curricula in various disciplines to support students' learning. Specifically, the use of databases can help students perform the following tasks:

- Manipulate a large amount of information.
- Organize and analyze information.
- Analyze content domains to uncover interrelationships.
- Acquire higher-order thinking skills such as categorizing, differentiating, analyzing and evaluating.
- Perform better in hypermedia PBL environments.

Additionally, the findings of this study also suggest some general guidelines that instructional designers and course developers may follow to create customized databases to be integrated into middle school curricula.

- Provide easy to use Graphic User Interface.

- Adjust the complexity of the database based on users' current cognitive developmental stage (ability level).
- Maintain a balance between cognitive load and database complexity.
- Build in scaffolding activities to provide users sufficient guidance and support.
- Provide alternative routes to accommodate different learning styles.

LIMITATIONS OF THE STUDY

There are two limitations on the generalizability of the findings of this study. First, the database tool examined in this study is designed for specific use in Alien Rescue, a multimedia PBL learning program. Therefore, this tool is more of a customized database program rather than a standardized database program such as Microsoft Access. As a result, the finding of this study may be difficult to be generalized to other settings when a standard database program or another customized database is used, or when the database is used in a traditional classroom or other interactive learning environments. It is the reader's responsibility to decide whether the findings in this study are applicable to his or her own teaching or research environment.

Second, Alien Rescue, the PBL program used in this study, provides a learning environment that is very different from traditional classrooms. The instructors were specifically trained to facilitate student learning in computer-enhanced, problem-based instruction. As a result, the findings of this study maybe difficult to replicate if the instructor is not experienced in using Alien Rescue program and facilitating this type of learning environment.

Finally, there is also a limitation on the technical part of the online database tool. Due to lack of programming support, the online database tool is separated from the rest of the cognitive tools in Alien Rescue. Learners had to quit the Alien Rescue program completely to go to the online database tool. This created a few management problems and caused some inconvenience to the learners. However, the future online version of the Alien Rescue program plans to incorporate this online database tool. Thus, database can be an integral part of the hypermedia PBL environment. Given the promising findings from this study, it is very likely that better learning outcomes could be achieved if database is part of Alien Rescue.

Appendix A: Task Difficulty Rating Scale

Please rate the difficulty level of the following tasks based on a 7-point scale: 1= extremely easy, 2= very easy, 3= easy, 4= neutral, 5= hard, 6= very hard, 7= extremely hard.

1. Organize my research data in Alien Rescue.

1 2 3 4 5 6 7

2. Retrieve and sort my research data in Alien Rescue.

1 2 3 4 5 6 7

3. Identify possible matches between aliens and planets.

1 2 3 4 5 6 7

4. Make comparisons between planets and aliens.

1 2 3 4 5 6 7

5. Eliminate unsuitable planets for aliens.

1 2 3 4 5 6 7

6. List rationales for specific recommendations in the solution form.

1 2 3 4 5 6 7

7. Learn to use the notebook tool or the database tool.

1 2 3 4 5 6 7

8. The overall experience in Alien Rescue

1 2 3 4 5 6 7

Appendix B: Factual Knowledge Test

Use the answer sheet provided to put down your answers to these questions.

1. Which of this world is a planet (not a moon)?
    - A. Charon
    - B. Io
    - C. Phobos
    - D. Uranus

2. Which of this world is a gas giant?
    - A. Venus
    - B. Saturn
    - C. Earth
    - D. Pluto

3. Which of the following world is a moon of Jupiter?
    - A. Europa
    - B. Mars
    - C. Charon
    - D. Neptune

4. Which of this world is farther from the sun than Saturn?
    - A. Mars
    - B. Earth’s moon
    - C. Mercury
    - D. Charon

5. Venus
    - A. is a gas giant
    - B. has two moons
    - C. has an atmosphere denser than Earth's
    - D. is very cold because of a greenhouse effect

6. Io
    - A. is the closest planet to the sun
    - B. has active volcanoes
    - C. has a solid core
    - D. is as cold as Pluto

7. Which of these worlds has the lowest surface gravity?

A. Earth
B. Triton
C. Jupiter
D. Mars

8. What is the difference between a moon and a planet?
   A. moons are closer to the sun than planets
   B. moons are smaller than planets
   C. planets have plant life and moons do not
   D. moons orbit planets but planets do not orbit moons

9. Which of the following does an atmosphere do for a world?
   A. causes volcanoes to erupt
   B. pushes heat out into space so the world doesn't get too hot
   C. protects it from meteors
   D. makes plant life develop on the world

10. Which of the following does a magnetic field do for a world?
   A. protects it from the solar wind
   B. lowers its temperature
   C. causes earthquakes
   D. gives it seasons

11. Craters are caused by
   A. water flowing over the surface of a world
   B. earthquakes
   C. magnetic fields
   D. meteor impacts

12. You are standing on the surface of a world and see the sun in the sky. The rest of the sky is black and you can see stars. What do you know about that world?
   A. It is a gas giant.
   B. It is one of the worlds in the inner solar system.
   C. It has no atmosphere.
   D. It has no magnetic field.

13. Which of the following is **NOT** the name of a temperature scale?
   A. Kelvin
   B. Fahrenheit
   C. Titan
   D. Celsius

14. Ice

A. can be made of many substances, not just water
B. covers most of the surface of Io
C. melts at 100 K
D. is an element

15. Which of these instruments can be used to learn about temperature on a world?

A. seismograph
B. RADAR
C. infrared camera
D. mass spectrometer

16. Imagine that you need to determine whether or not a moon's surface has carbon. What instrument would you use?

A. wide angle camera
B. mass spectrometer
C. seismograph
D. barometer

17. Scientists want to measure the pressure of Mars' atmosphere. What instrument would they use?

A. barometer
B. thermometer
C. magnetometer
D. infrared camera

18. Suppose that you want to take closeup pictures of features on the surface of Callisto, but you can only afford to send an orbiter. What instrument would you include?

A. infrared camera
B. narrow angle camera
C. mass spectrometer
D. barometer

19. You need to design a probe to go to Titan to find out if it has a magnetic field or earthquakes. Which of the following would you choose to include on your probe?

A. a battery and a solar panel
B. an infrared camera and a magnetometer
C. a barometer and a seismograph
D. a magnetometer and a seismograph

20. Will a mass spectrometer work on a flyby probe?

A. Yes, because mass spectrometers take readings from space
B. Yes, but only if you include solar panels
C. No, because mass spectrometers must come into contact with the substance they analyze
D. No, because mass spectrometers only work on orbiters and landers

21. Scientists want to gain more accurate information about the atmosphere of Venus, especially what it's made of. What type of probe would they use and what instrument would they include?

A. an orbiter with an infrared camera
B. a flyby with a mass spectrometer
C. a lander with a mass spectrometer
D. a lander with a barometer

22. At a temperature of absolute zero

A. water melts
B. atoms stop moving
C. carbon changes from a liquid to a solid
D. matter is destroyed

23. Water boils at which of the following temperatures? (Remember to think about the different temperature scales.)

A. 32 degrees C
B. 100 degrees C
C. 100 degrees F
D. 200 K

24. Which of these could be considered a "signature" for an element?

A. a seismograph
B. barometric pressure
C. an infrared picture
D. a spectrogram

25. A world will have a magnetic field if

A. it has a thick atmosphere
B. it has liquid water
C. it has a core made of liquid metal
D. it is close to the sun

Appendix C: Transfer Test

1st Email Message From Mia Salerno

From: Mia Salerno, U.S Fish & Wildlife Service
To: Space Station Paloma Young Scientists

My name is Mia Salerno. I am a biologist studying the Barton Springs Salamander. As you may know, it is an endangered species. Data I have been collecting shows that the salamander is in danger of extinction because of water pollution and the many people who swim in the area where they salamanders live.

The Barton Springs salamander is an amphibian, and looks somewhat like a lizard. It has a long slender body about 2.5 inches long with gills on its neck for breathing in water. It has short legs and usually bends its body from side to side to give it as wide as possible a movement for its feet. These salamanders must live in deep water that moves quickly, and they like spring fed pools the best. Right now, they live only in pools fed by Barton Springs in Austin, Texas. The water temperature must be between 50F-68F, and they cannot survive in water warmer than that. Salamanders tend to be shy, coming out at night to feed. They eat earthworms and brine shrimp. They need a rocky and sandy river bottom. Leaves and rotting debris can pollute the water, making it difficult for salamanders to survive. Salamander eggs usually hatch in November, March, and April.

Since Barton Springs area is so small, we would like to try to introduce the salamander to a different location to see if it can survive there. We are considering the following locations: Lake LBJ. However, we still need to collect information about these locations. Could you please help me with the following tasks so that I will know what information I need to collect?

Thank you for your help.
Mia Salerno

(1) Carefully read through Mia's message and find the information that is **important** for you to find a new home for salamander. Then, categorize the information you gathered, and put your category labels and the corresponding information into the following table.

Categories	**Information on Salamander**

(2) Some information from Mia's message is **not important** for us in order to find them a new home. List three examples of those useless information and explain why you think they are not useful.

1. ______________________________
   ____
2. ______________________________
   ____
3. ______________________________
   ____

2nd Email Message From Mia Salerno

From: Mia Salerno, U.S Fish & Wildlife Service
To: Space Station Paloma Young Scientists

Here is additional information I collected about Lake LBJ. Please help me decide whether Lake LBJ is a good home for salamander.

Lake LBJ is located northwest of Austin, Texas, and was named after Lyndon B. Johnson, former president of the United States. It is just over 21 miles long and has a maximum width of 10,800 feet. Tourists from all over Texas come here to take advantage of this beautiful lake. Water skiing and other sports are very popular here. The irregular shore line makes Lake LBJ attractive to boaters and fishermen. There is a rich variety of aquatic life, particularly bass, trout, and shrimp. The temperature of the lake ranges from 62 to 68 Fahrenheit. Lake LBJ is about 40 feet deep. In the past, the lake suffered from pollution from Austin, though recent efforts have helped, and lake LBJ is much cleaner than it was fifteen years ago. The most beautiful months for visiting the lake are March, April, May and June when the flowers are blooming.

Thank you for your help.
Mia Salerno

(3) Is there any **missing** information from Mia's message that your need to make a decision on whether we should place salamander in Lake LBJ? Circle your answer. If your answer is yes, explain why you need that information.

YES____
____
____
____
______

NO

(4) Please make a final decision on whether Lake LBJ is a good home for salamander. Refer to the previous table if needed. Please give plenty explanation on your decision.

Species: Salamander
Habitat: Lake LBJ
Recommendation:____
____
____
____
____
____
____

Appendix D: Interview Questions

1. What do you think of the database tool? Do you like it? Why?

2. Is it the database tool helpful to your research? If yes, how? If no, why?

3. How will you conduct your research if you don't have this database tool?

4. Could you please give me a list of the things you can do with this database tool?

5. How long did it take for you to learn to the use the database tool? Do you think it worth the effort?

6. Is the database tool hard to use? Why?

7. Do you think the database tool slow you down in your research process? Why or why not?

8. Do you think the database tool adds another task for you to do in Alien Rescue, and it's too much for you to handle? Explain.

1. Do you like Alien Rescue? Why?

2. How do you organize you research data in Alien Rescue? Is it convenient for you?

3. If we can build some tools in AR to help you organize your research data, what would you want it be? Please explain.

Appendix E: Paper-based Database Tool Sample

A. Elimination Chart

	Akona	Eolani	Jakala-Tay	Kaylid	Sylcari	Wroft
Callisto						
Charon						
Deimos						
Europa						
Ganymede						
Io						
Jupiter						
Mars						
Mercury						
Moon						
Neptune						
Phobos						
Pluto						
Saturn						
Sun						
Titan						
Triton						
Uranus						
Venus						

B. Information Table (Sample)

Akona
Body: **Food:** **Habitat:**

IO
Surface: **Temperature:** **Atmosphere:** **Water:** **Gravity:** **Minerals:** **Magnetic fields:** **Seismic activity:**

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